Quality-adaptive Prefetching for Interactive Branched Video using HTTP-based Adaptive Streaming

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We have all seen a movie that (in our taste) is...

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too sad

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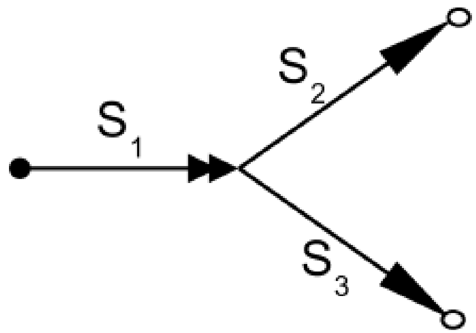

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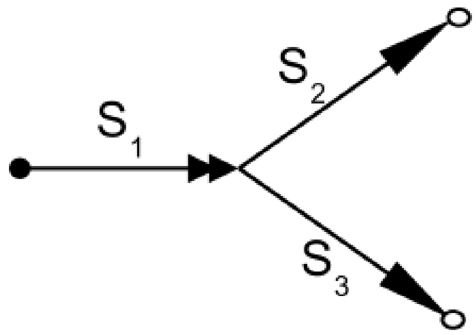

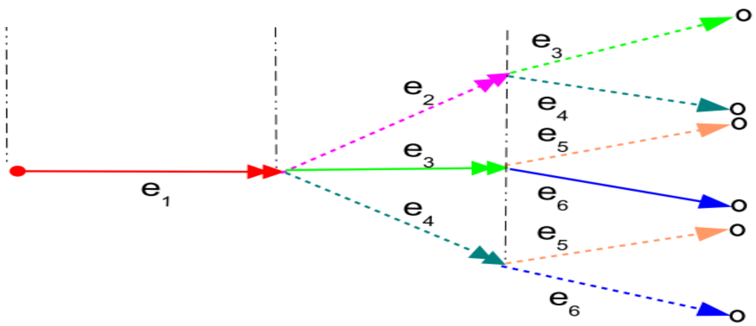

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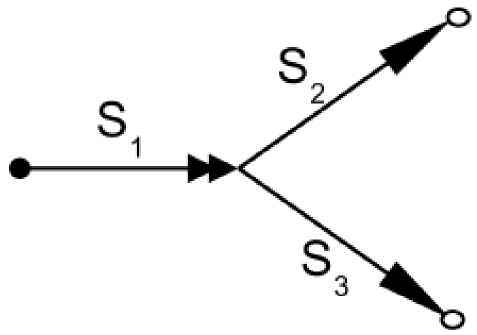

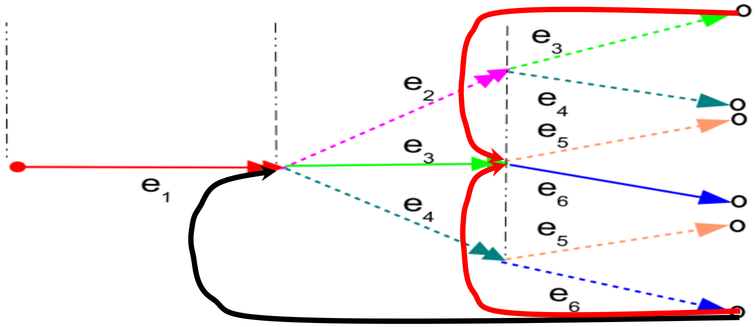

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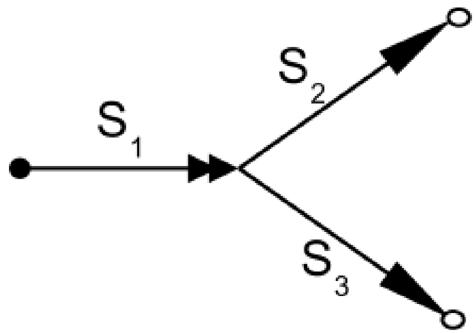

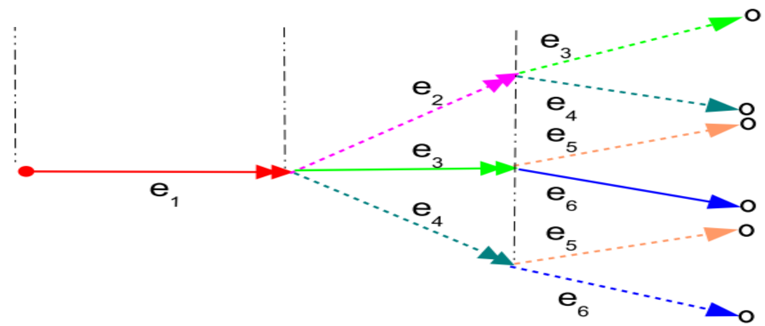

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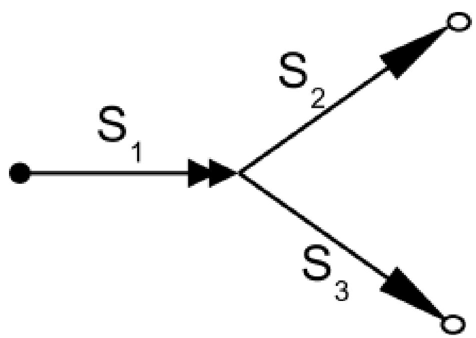

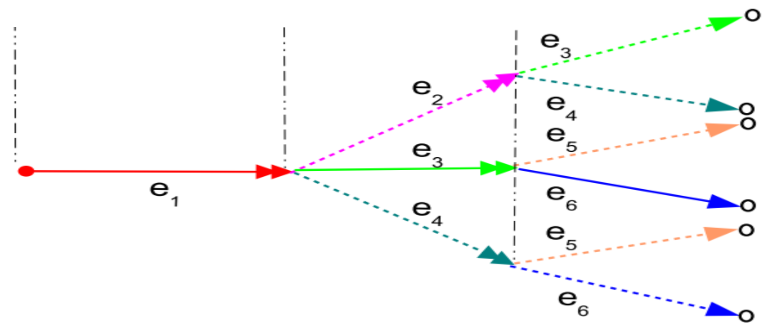

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… and even books!

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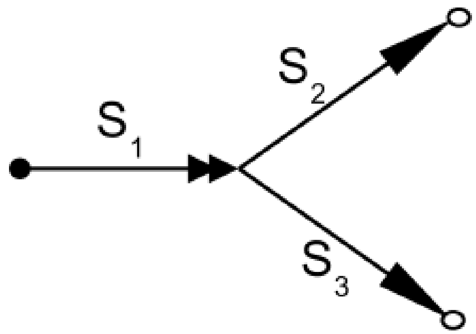

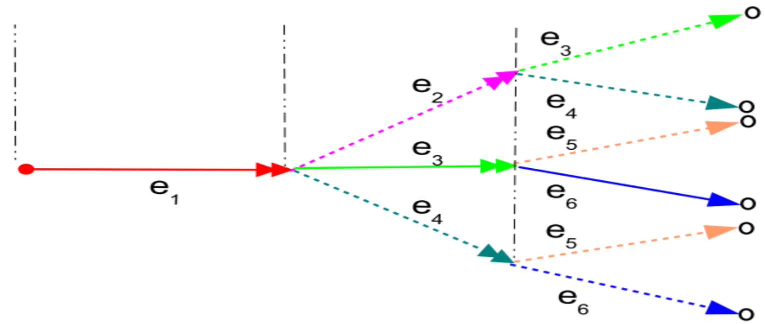

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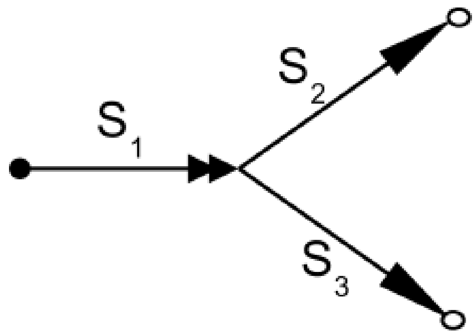

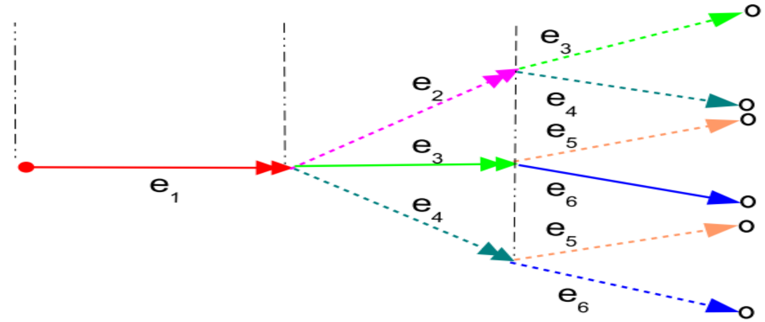

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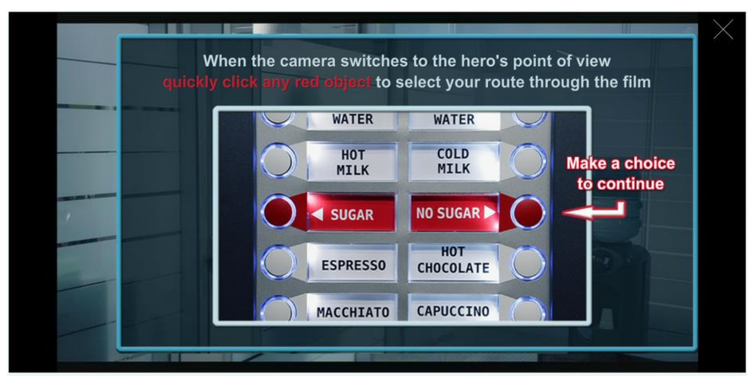

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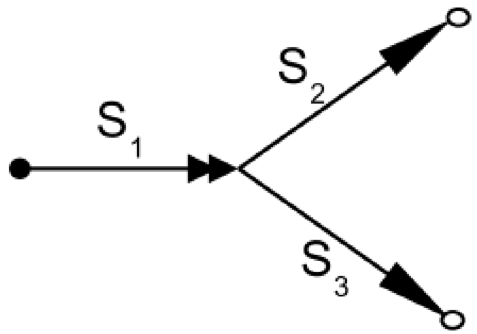

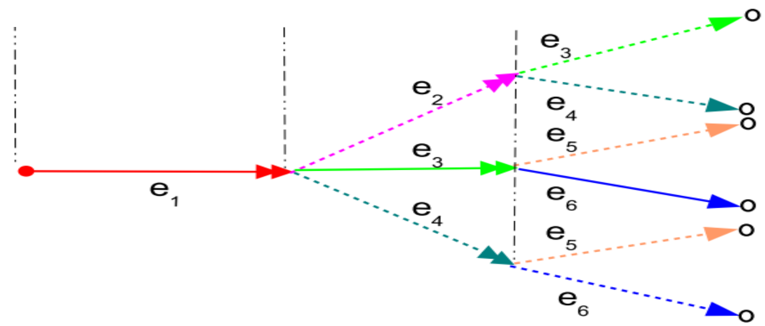

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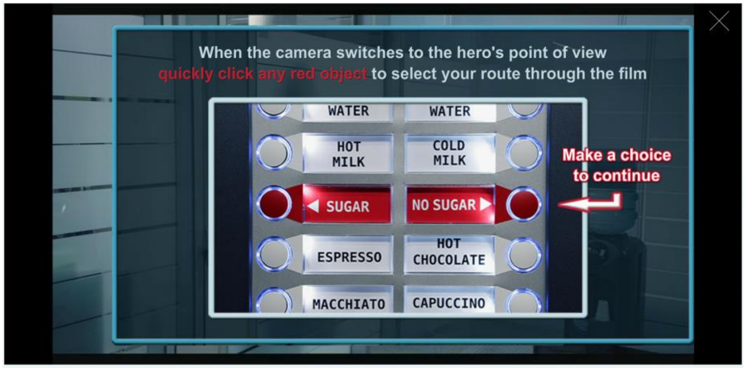

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Seamless Playback without Stalls

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  - Playback stalls and quality fluctuations

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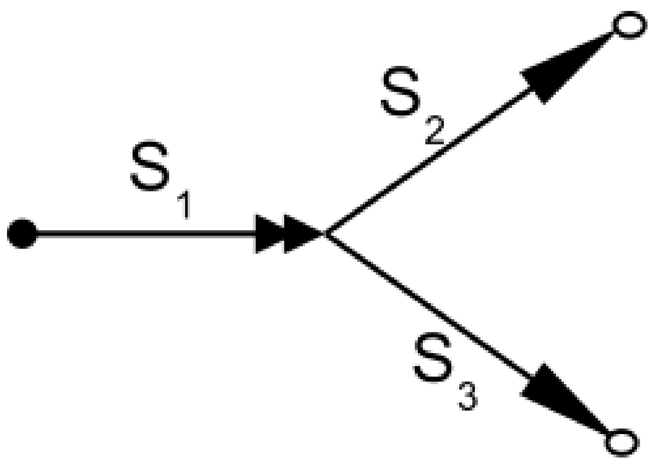

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[Krishnamoorthi et al., *ACM CCR* 2013]

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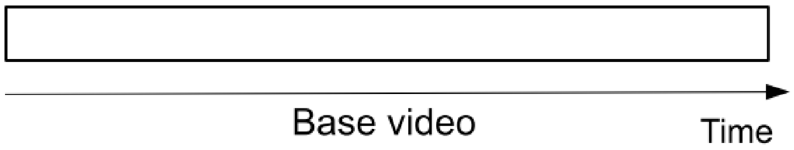

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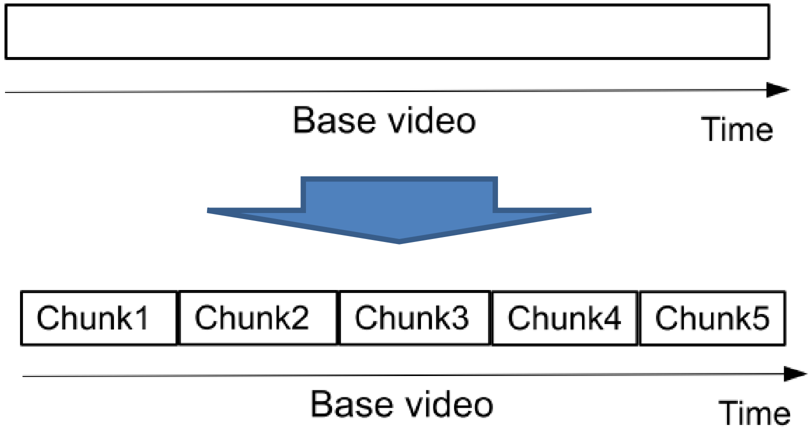

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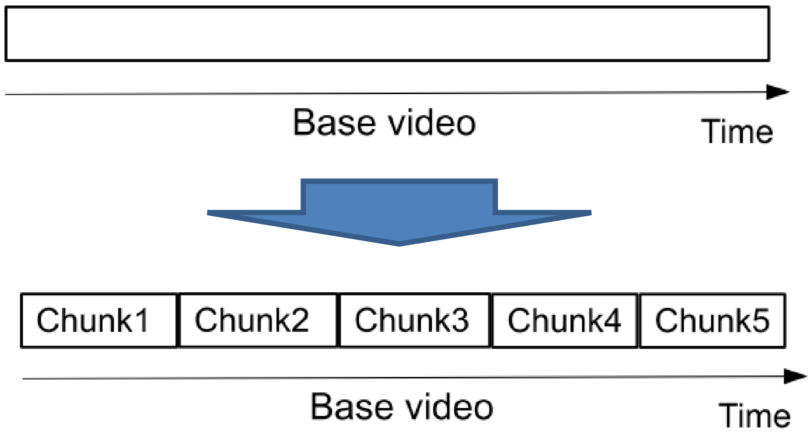

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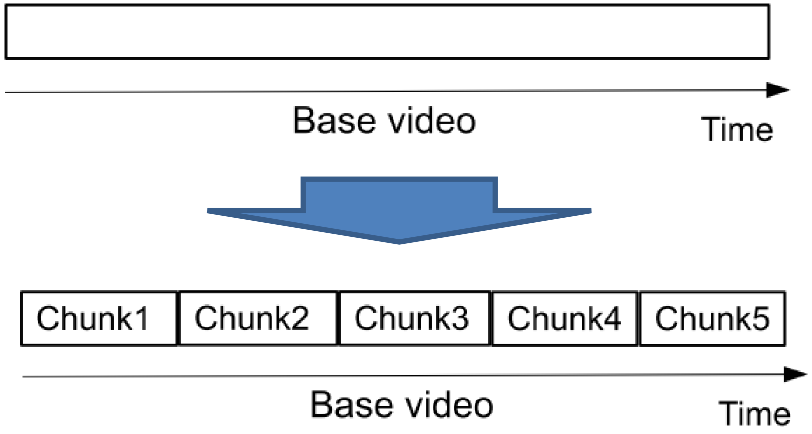

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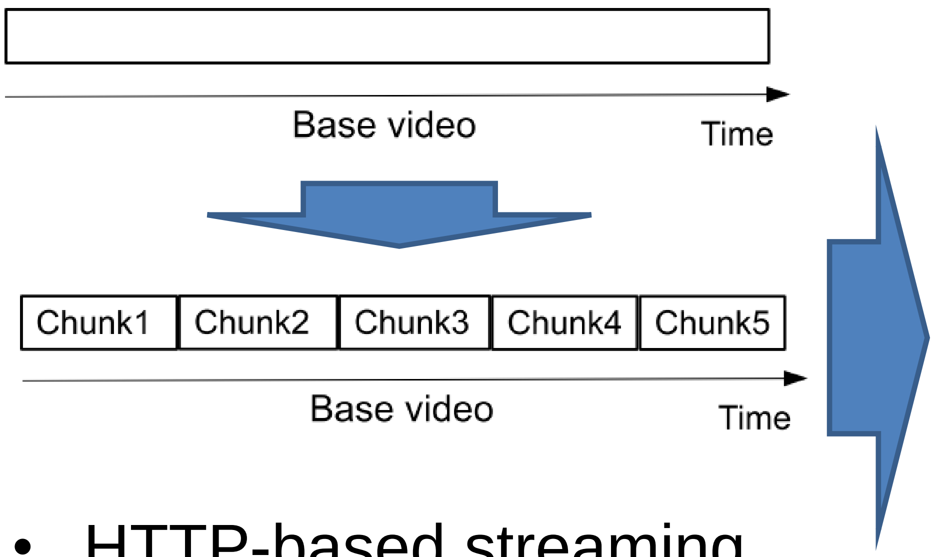

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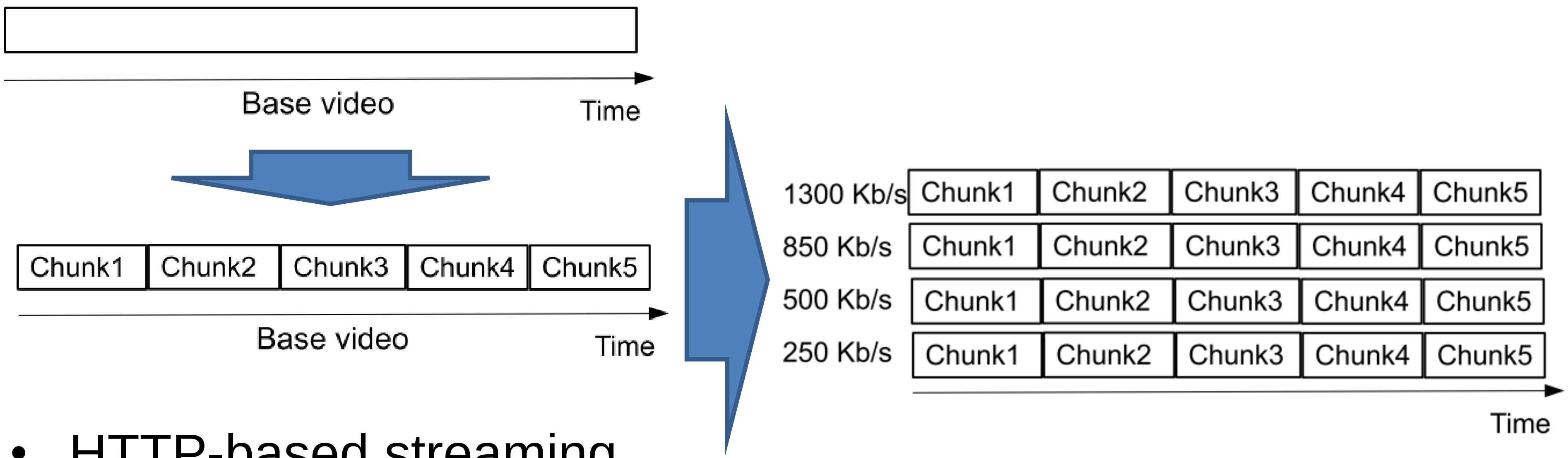

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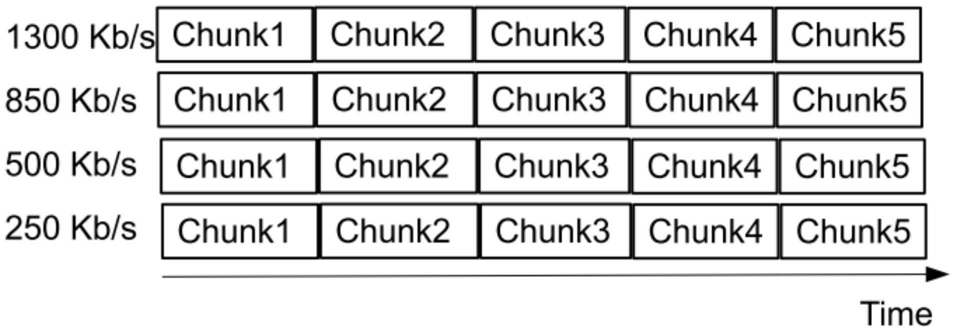

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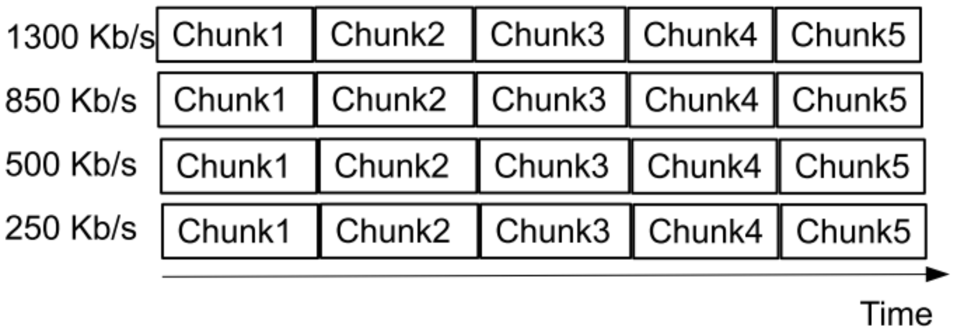

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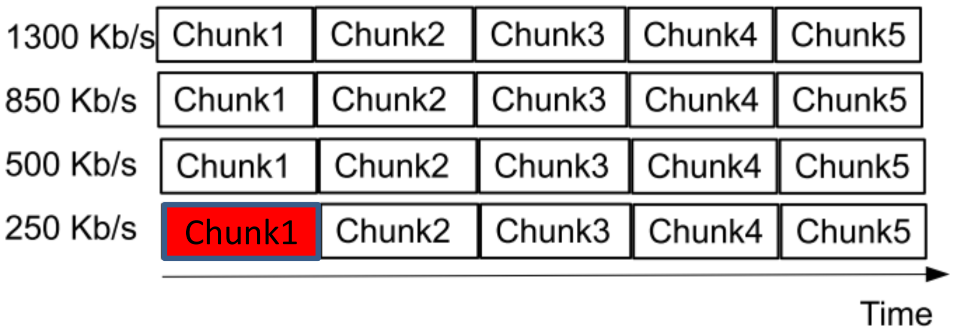

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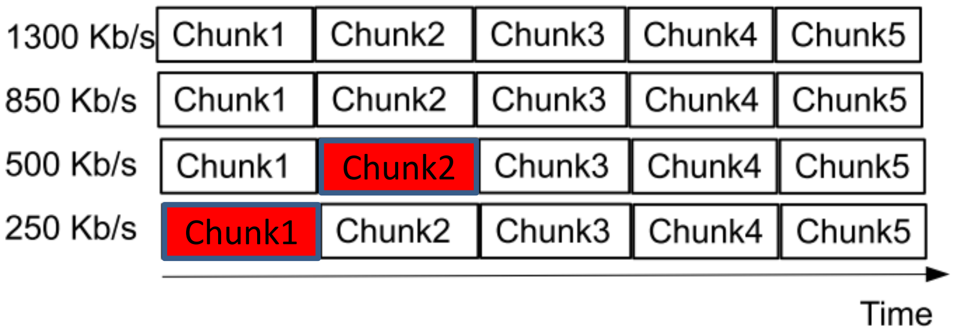

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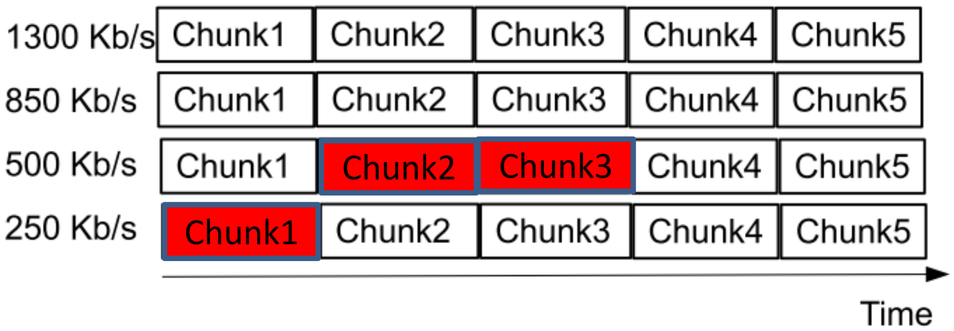

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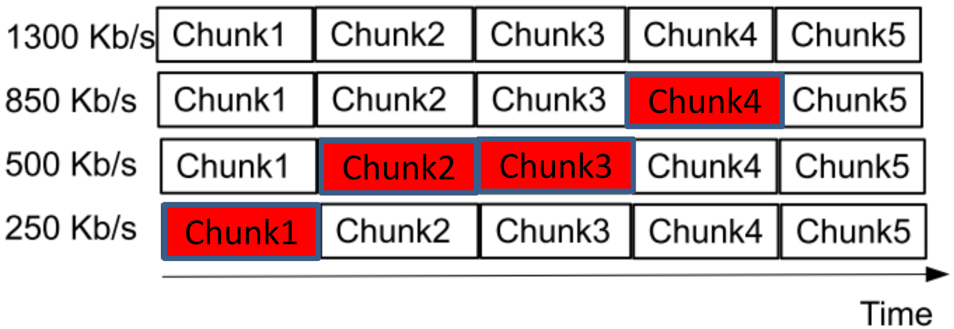

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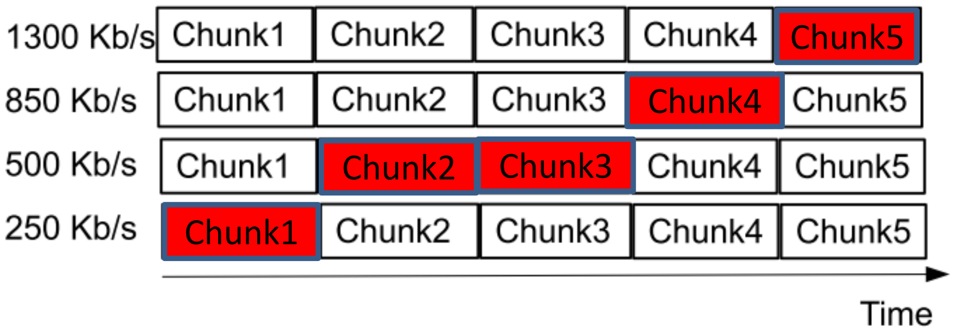

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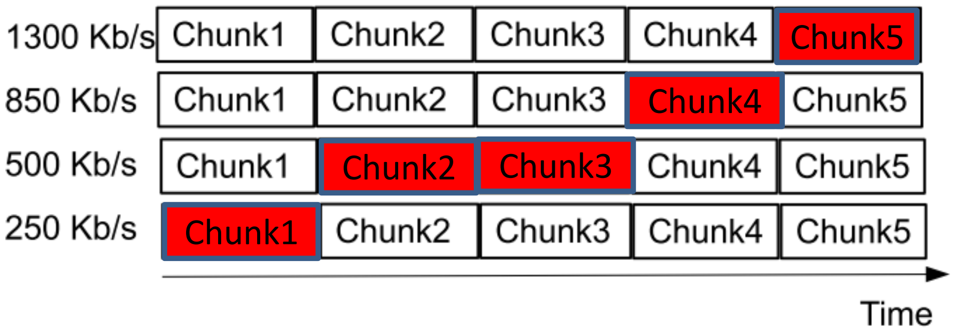

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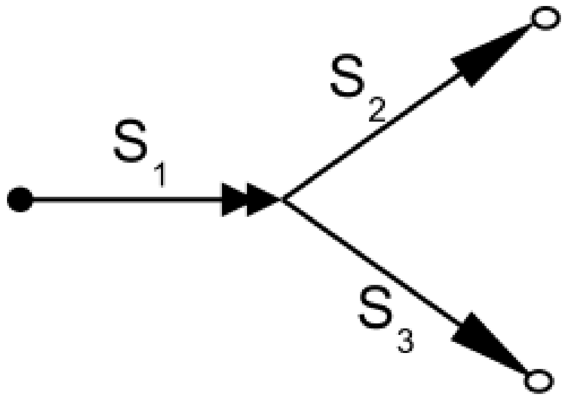

- Branched video and branch points

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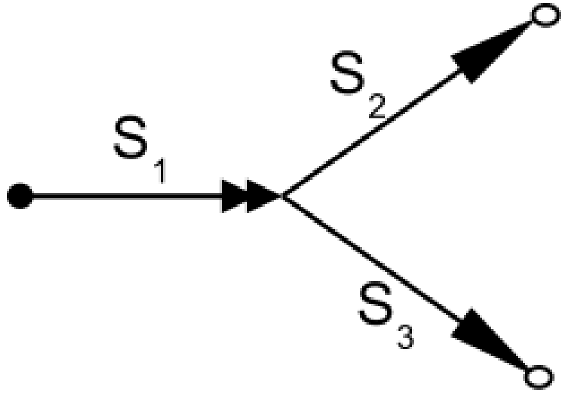

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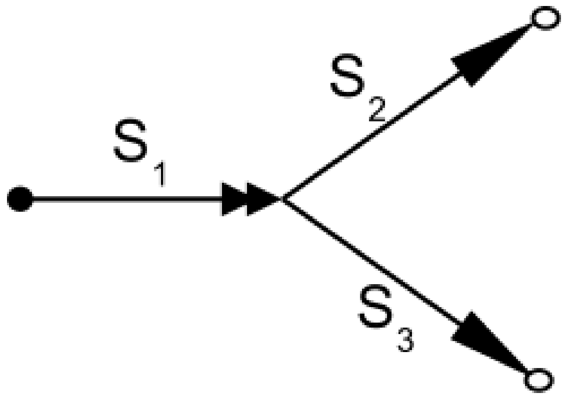

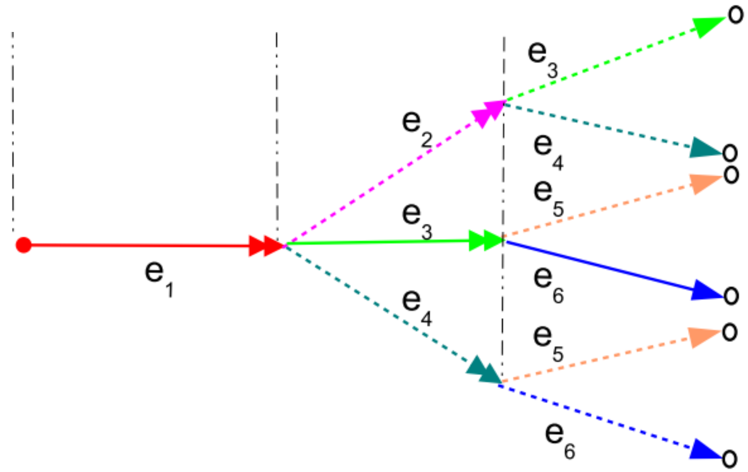

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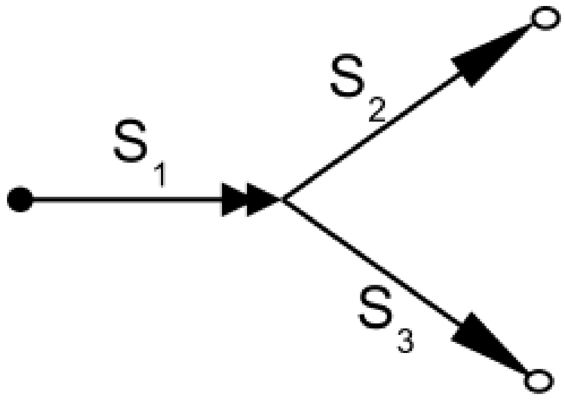

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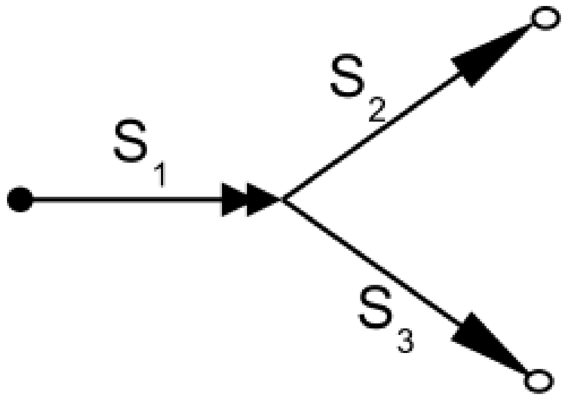

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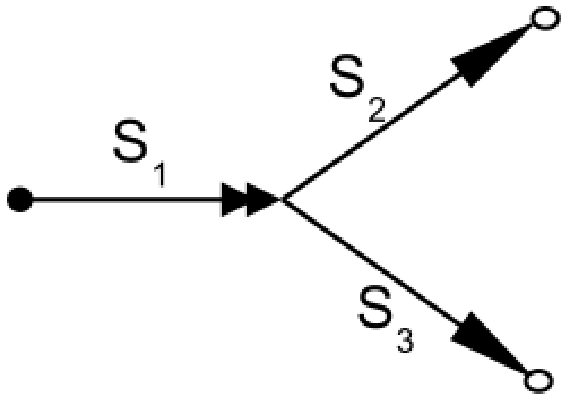

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- Segments

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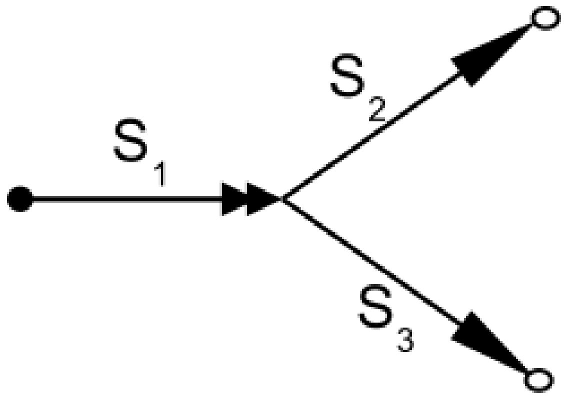

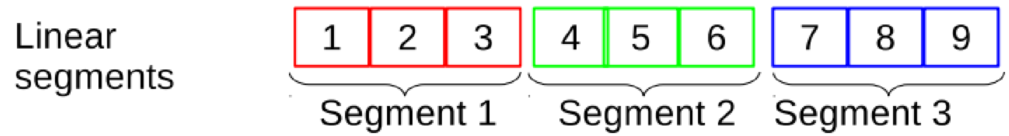

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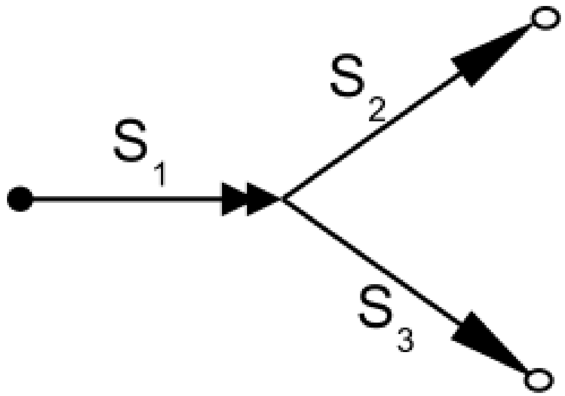

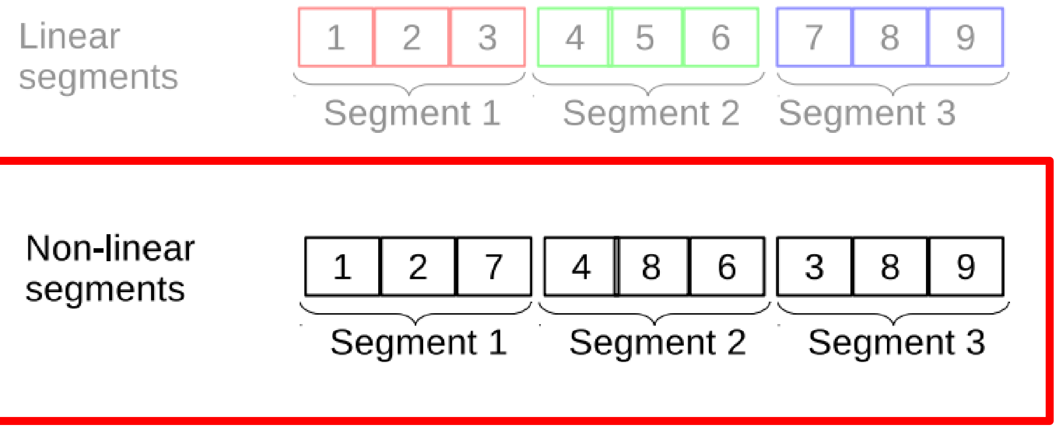

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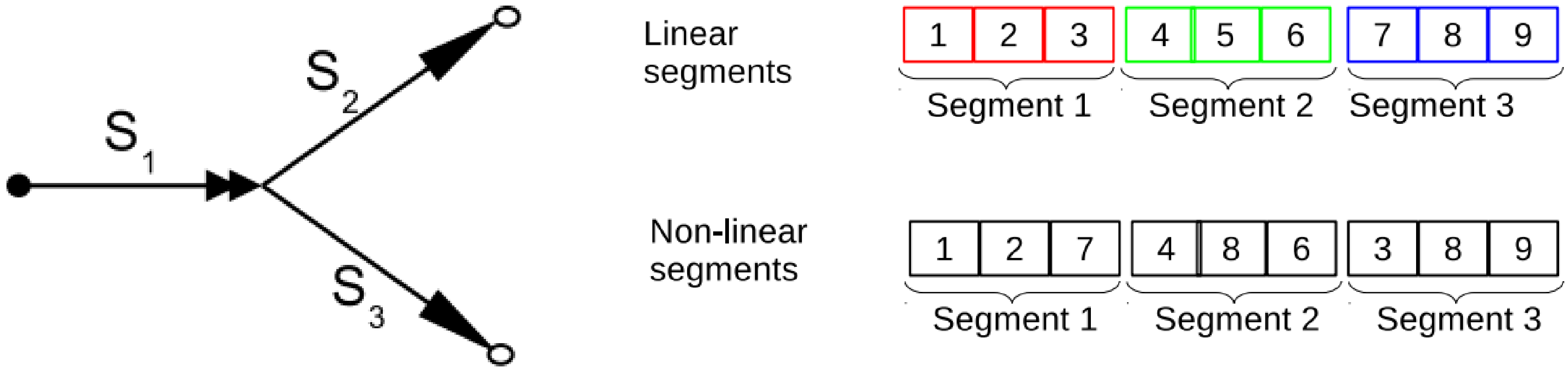

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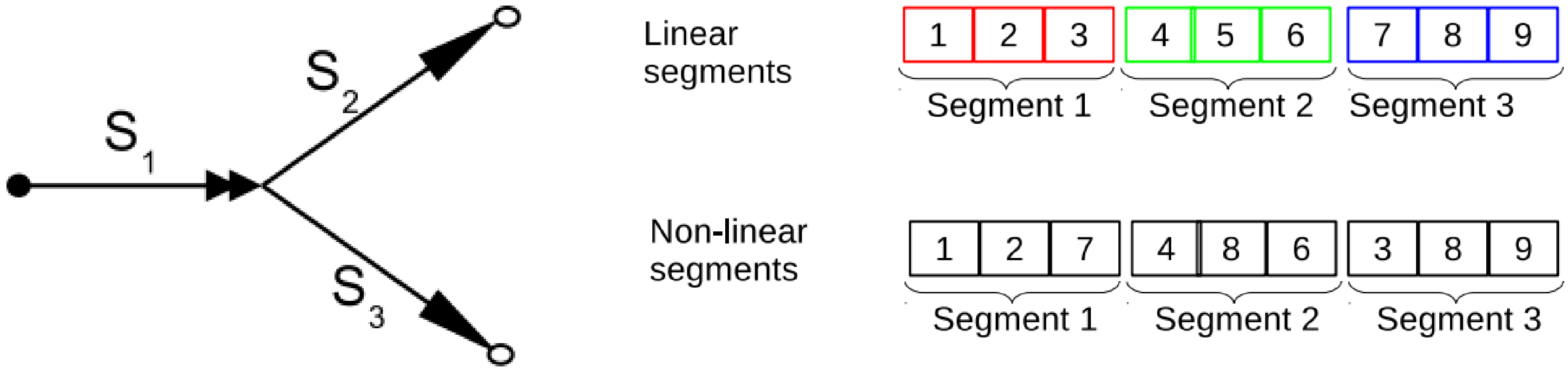

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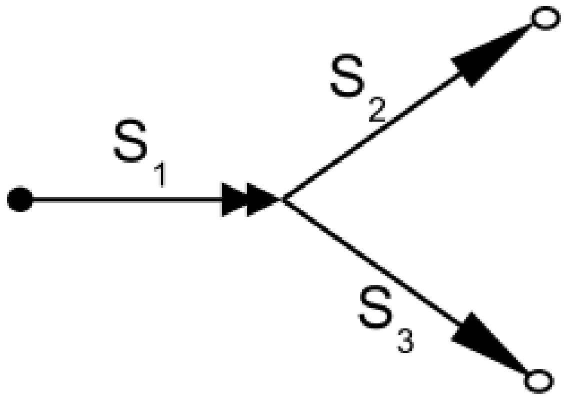

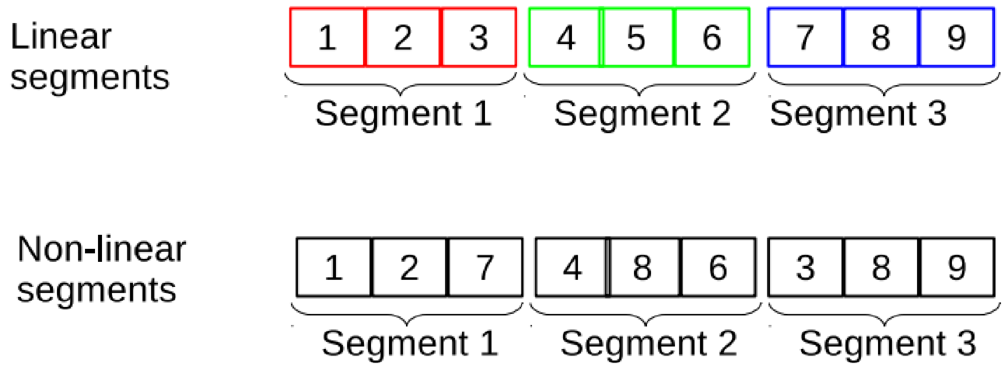

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Contributions

- We develop a simple analytic model which allows us to define the prefetching problem as an optimization problem
  - Maximizes expected playback quality while avoiding stalls
- Based on our findings, we design optimized policies that determine:
  1. When different chunks should be downloaded
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Problem Description and Constraints

- Problem: Maximize quality, given playback deadlines and bandwidth conditions

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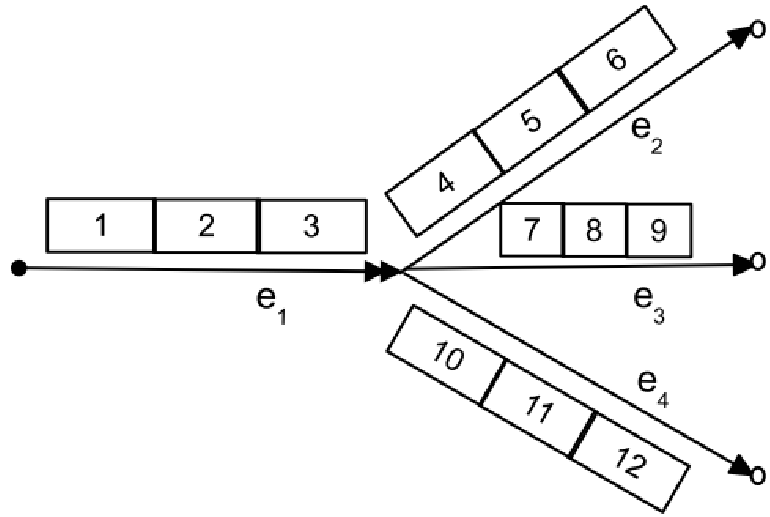

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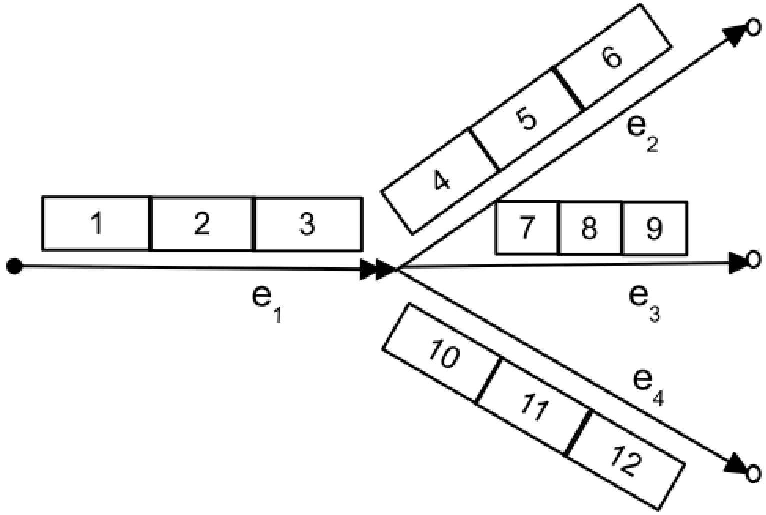
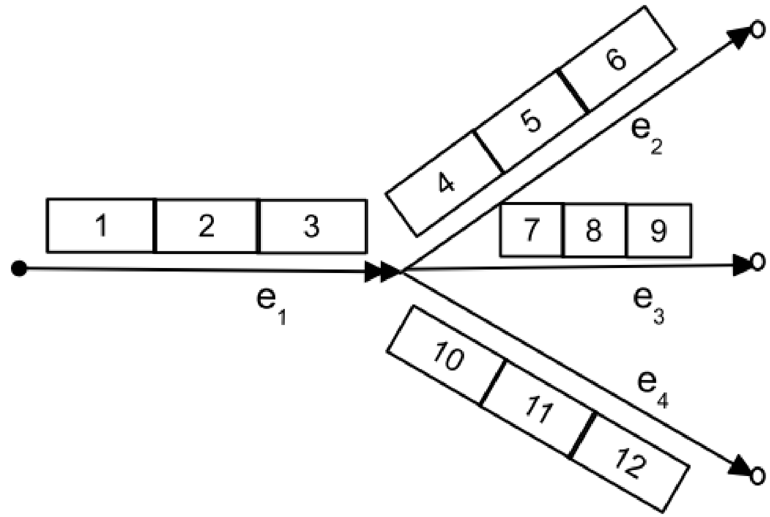


- Objective function

maximize playback quality

Problem Description and Constraints



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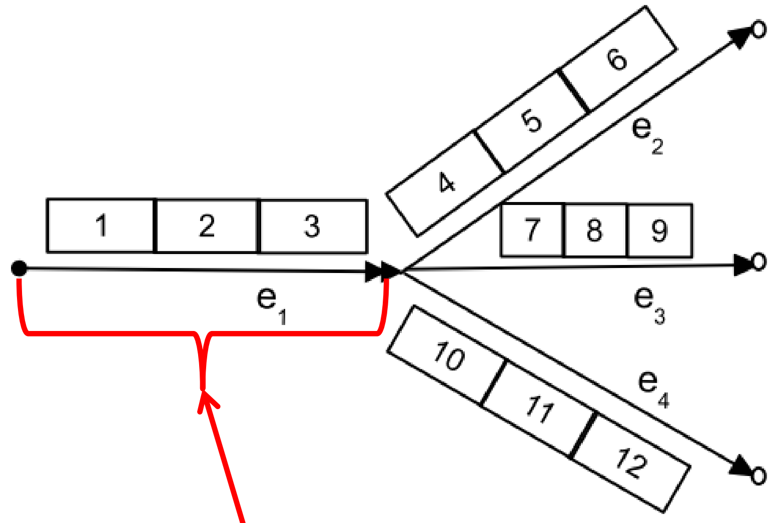

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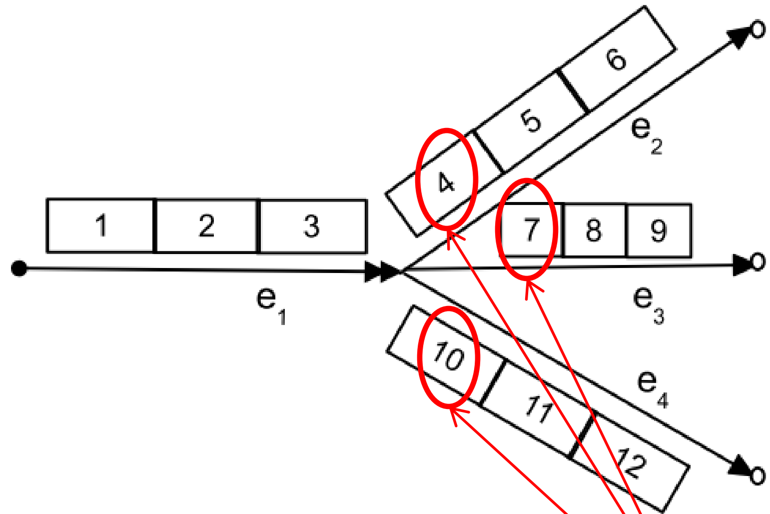
Current segment

Problem Description and Constraints



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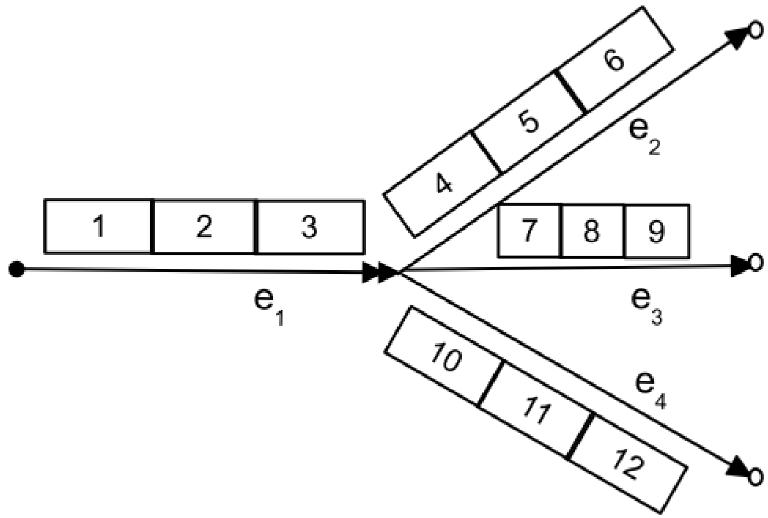
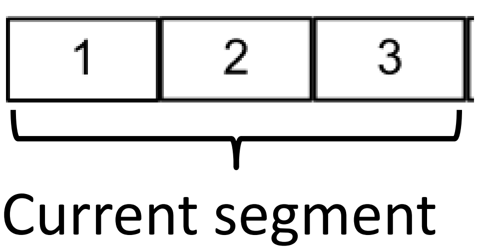
Beginning of next segment

Problem Description and Constraints



- Download order: round robin (optimal)



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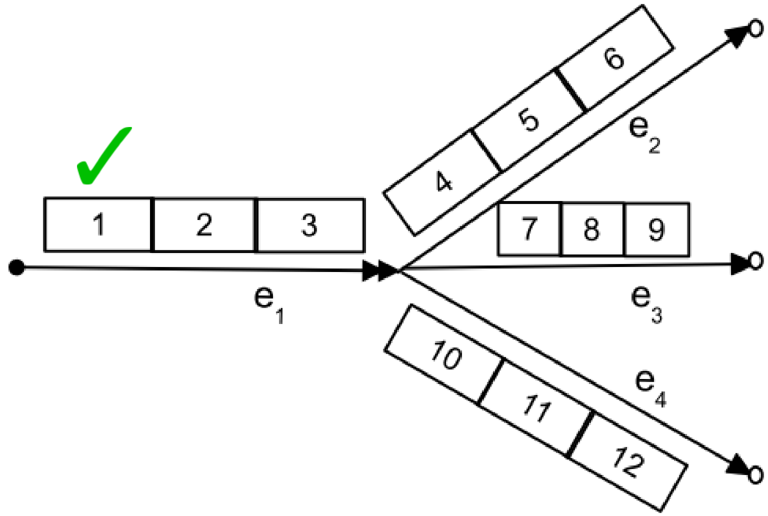

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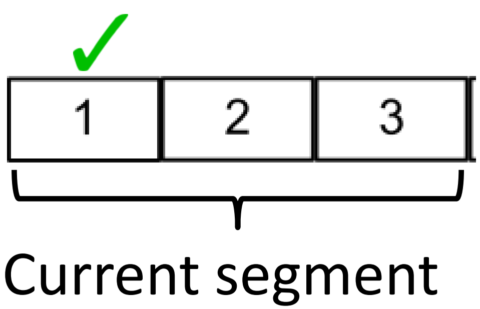

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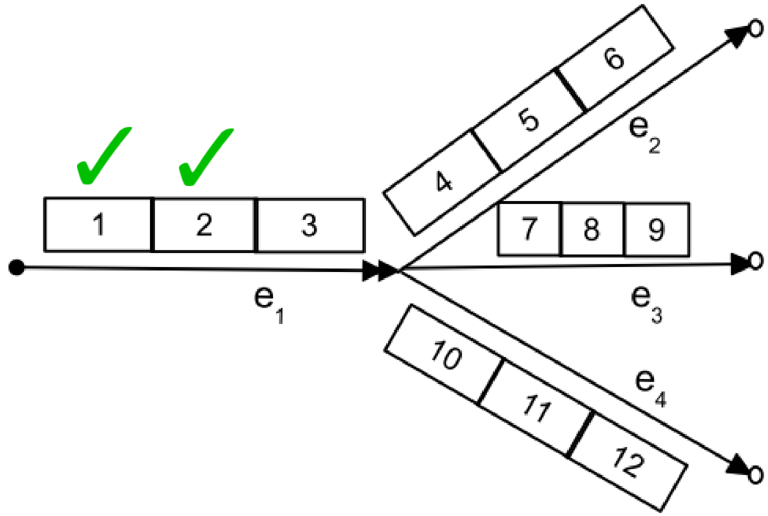

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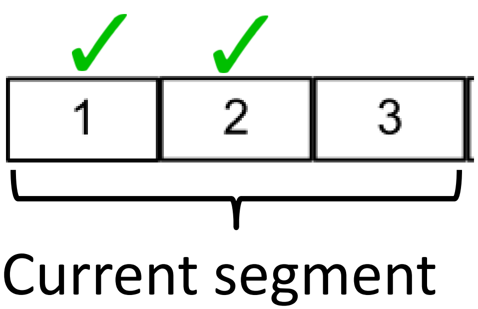

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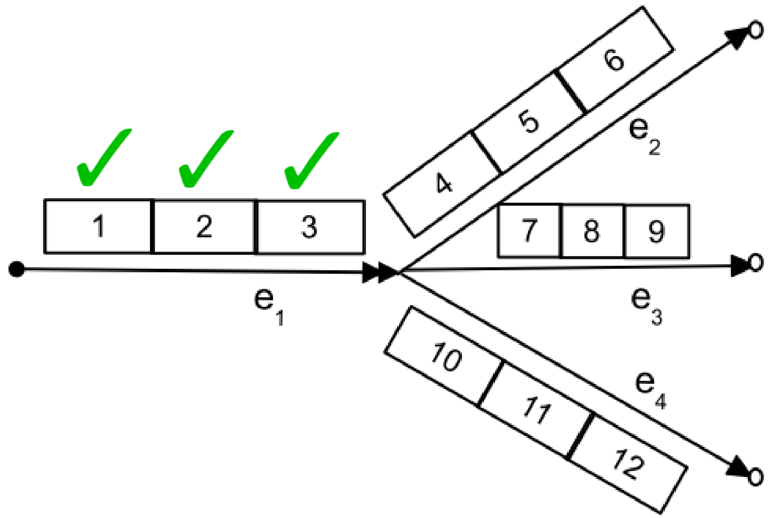

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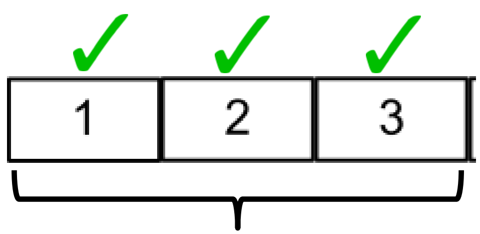
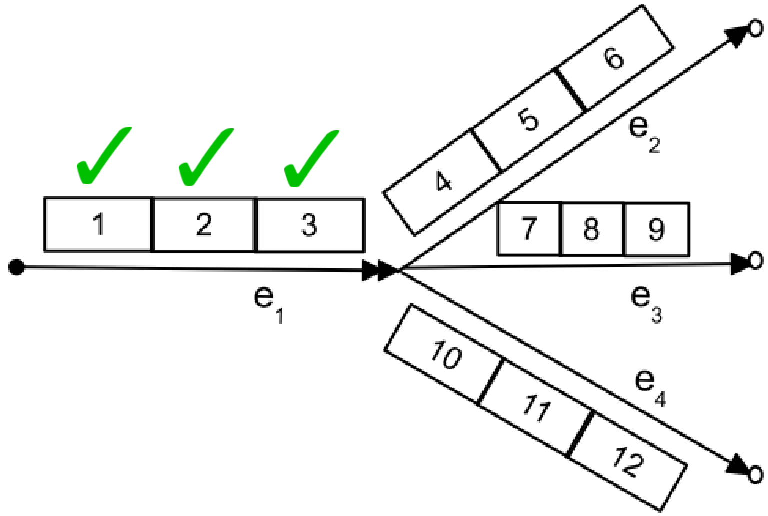


Current segment

Problem Description and Constraints



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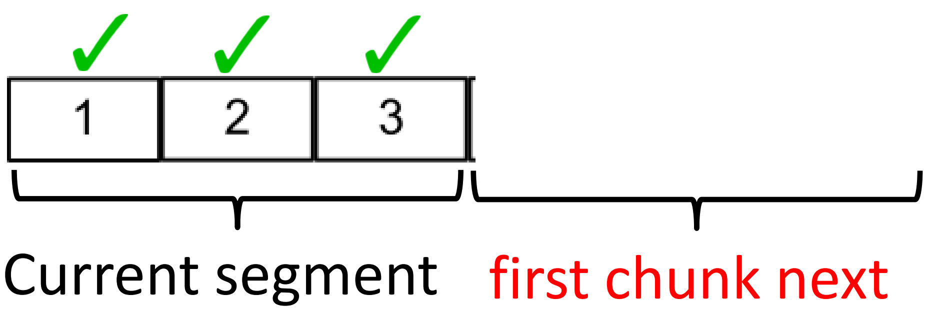

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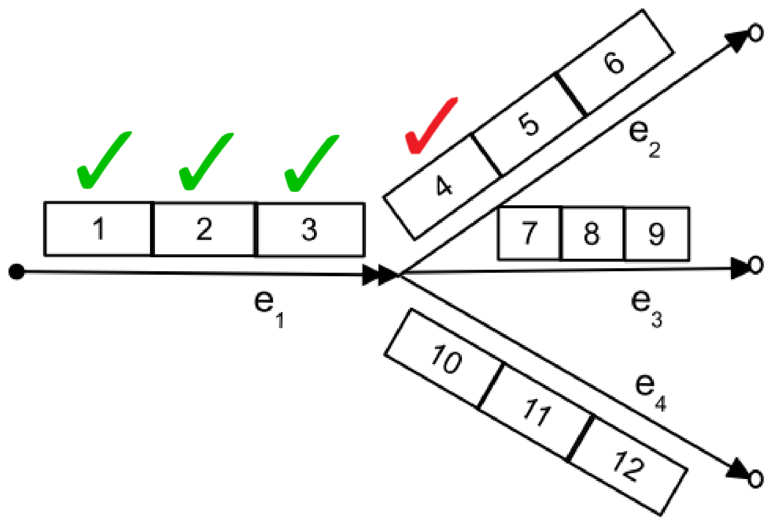

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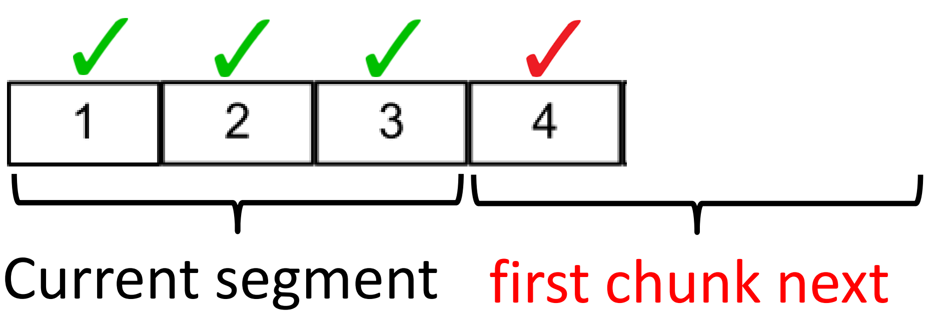

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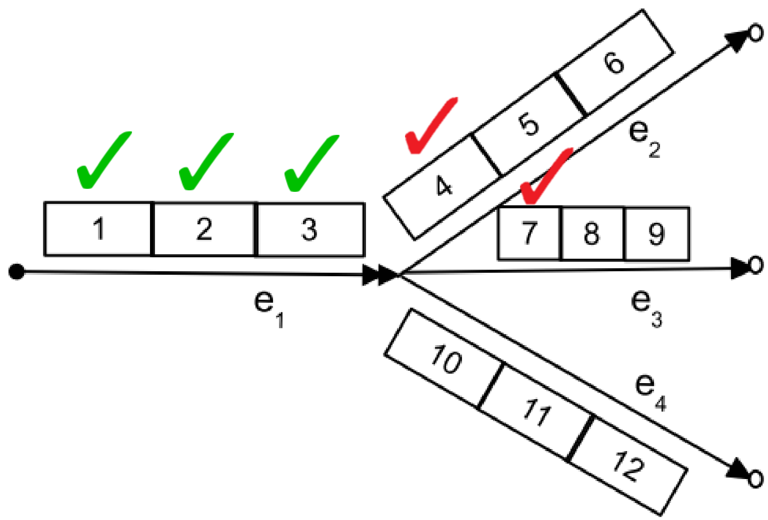

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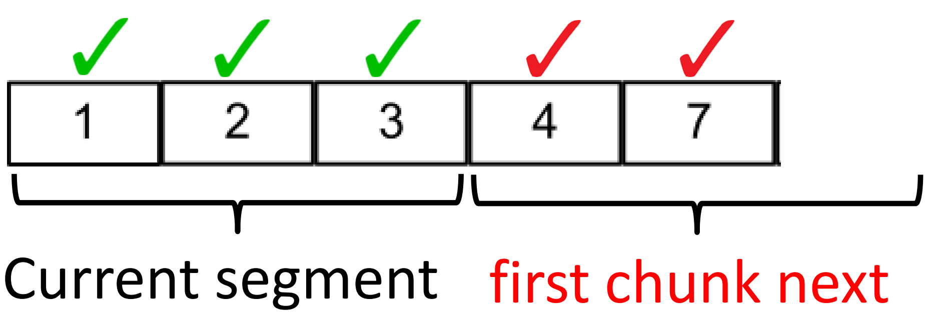

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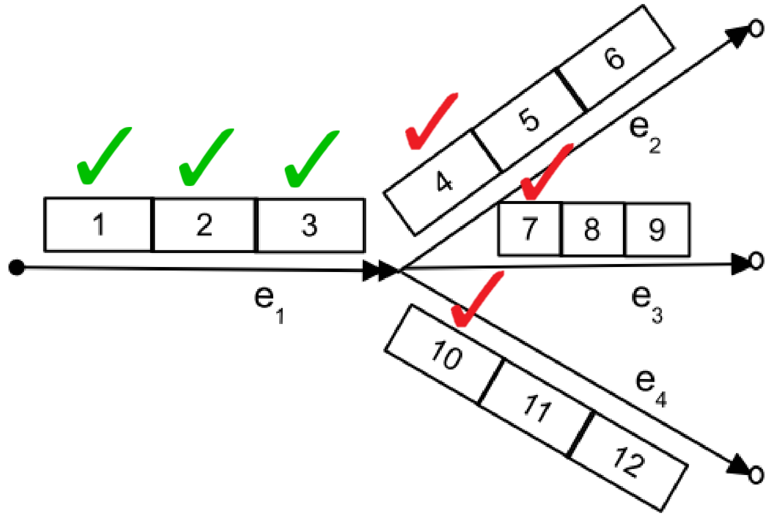

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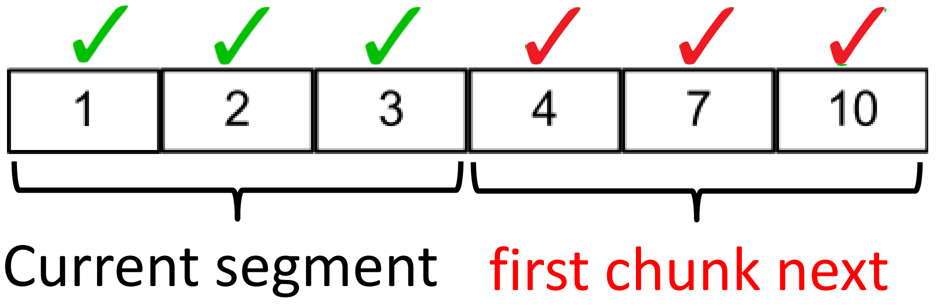

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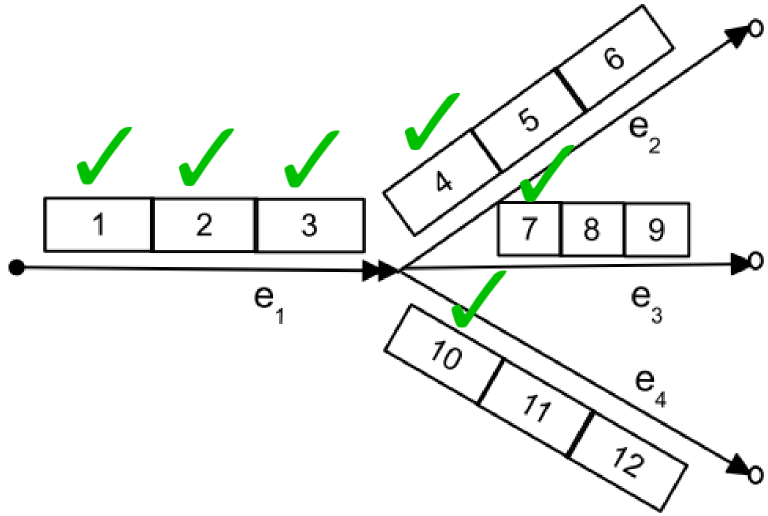

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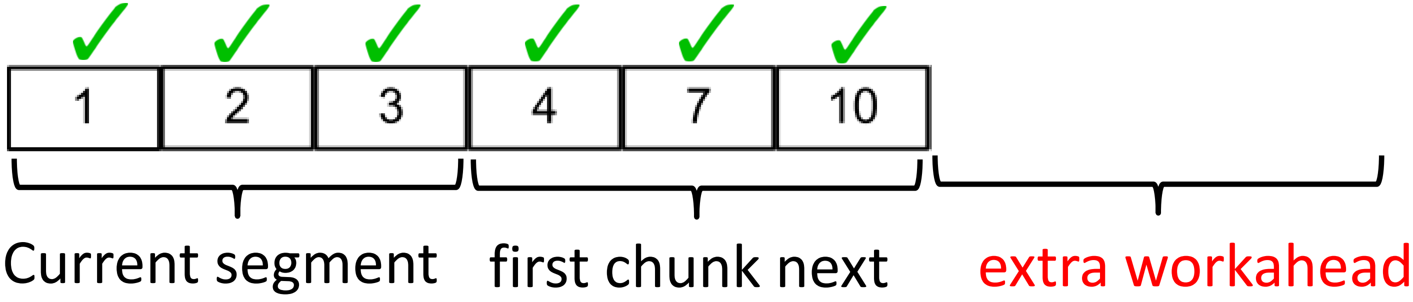

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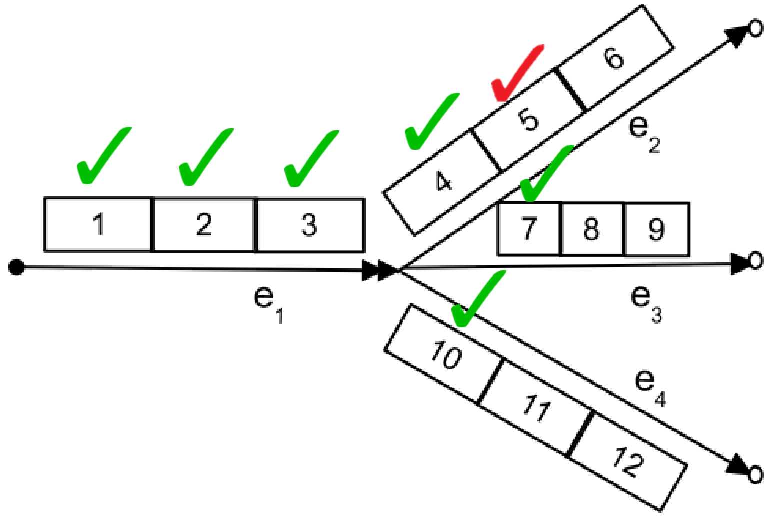

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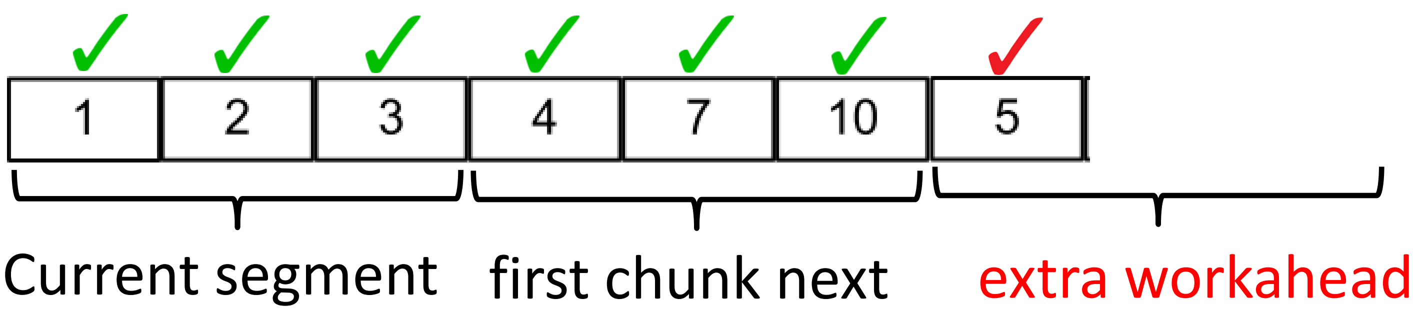

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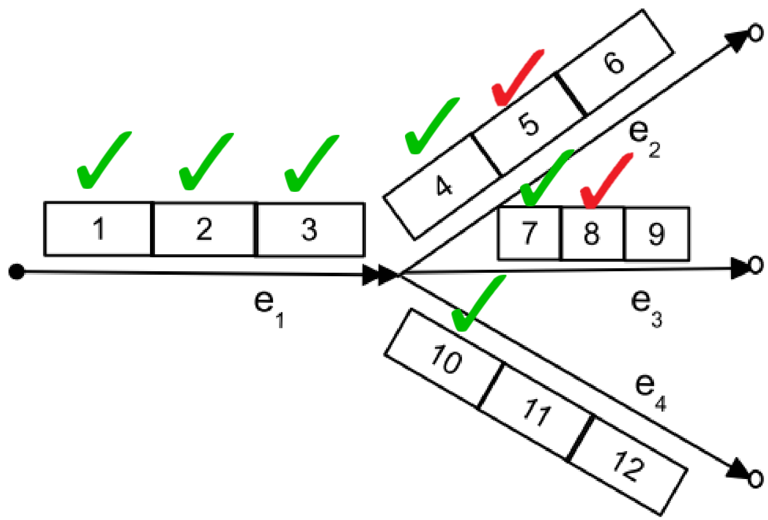

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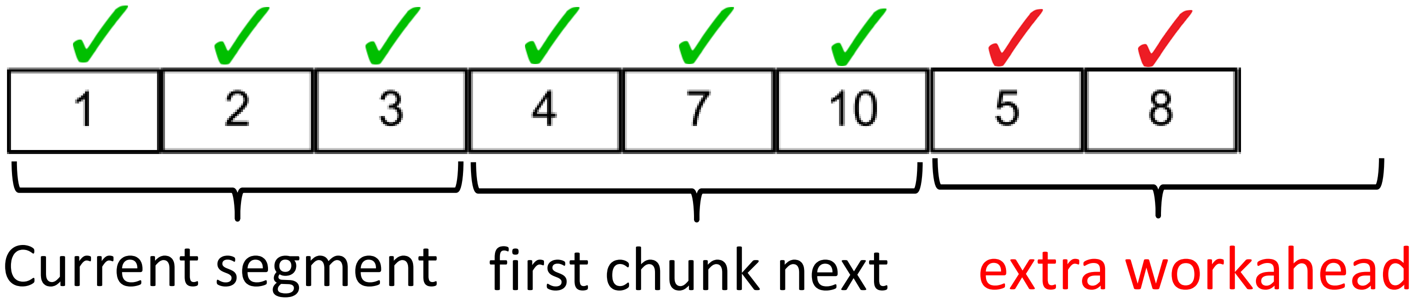

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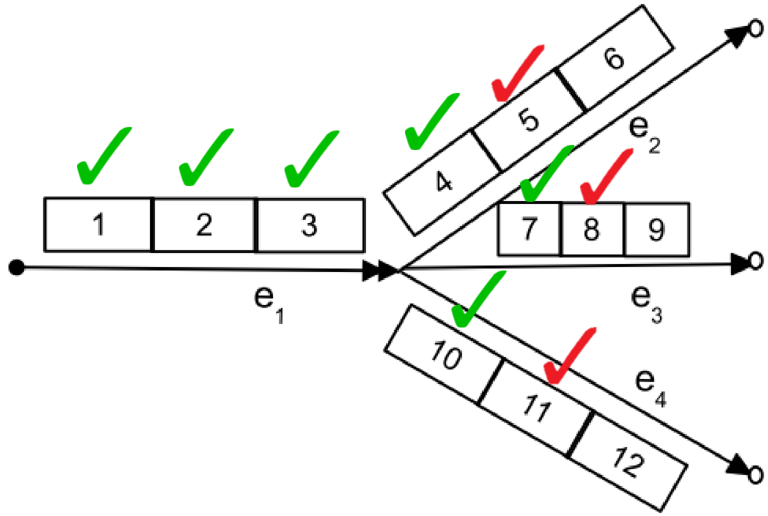

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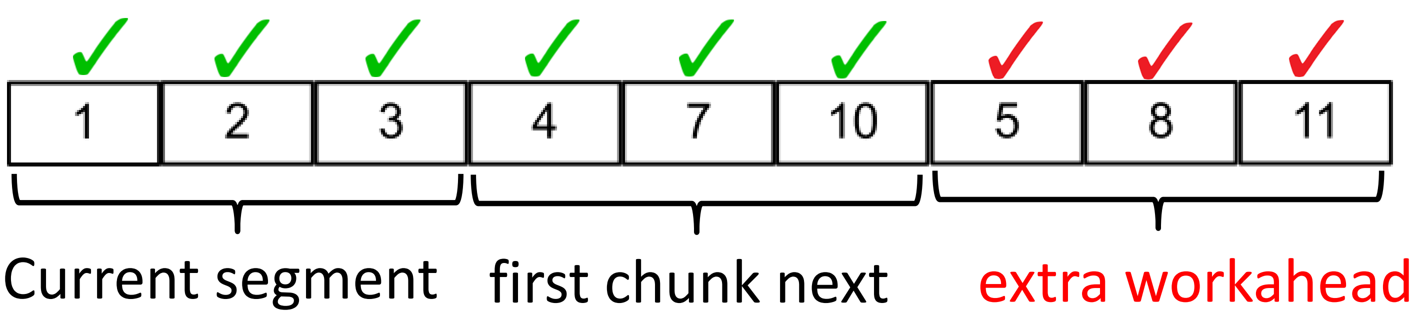

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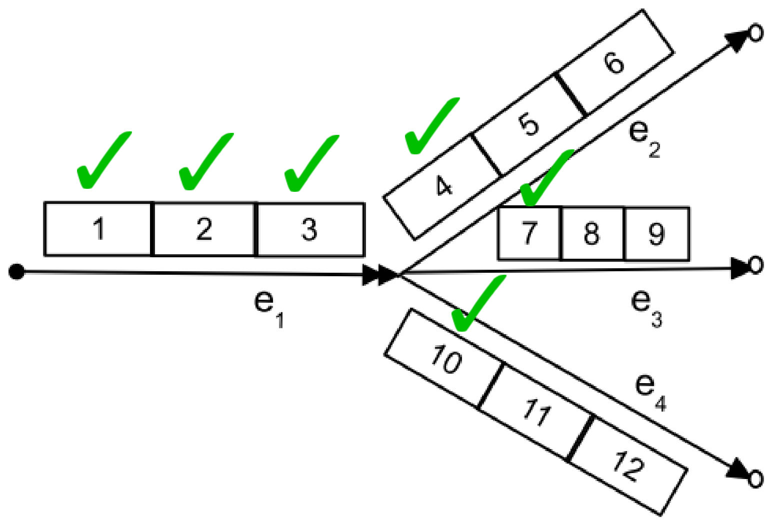

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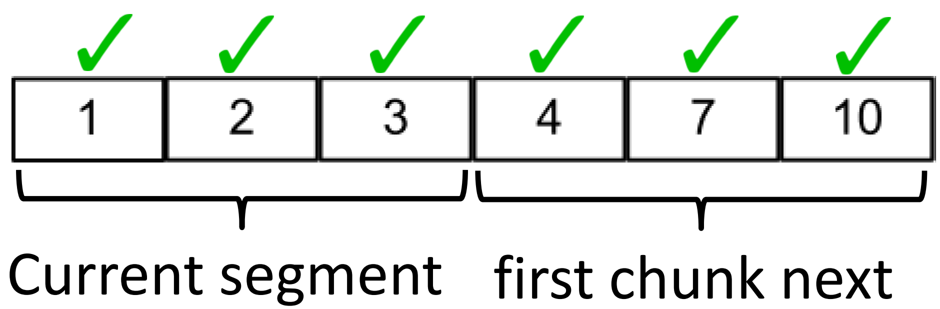

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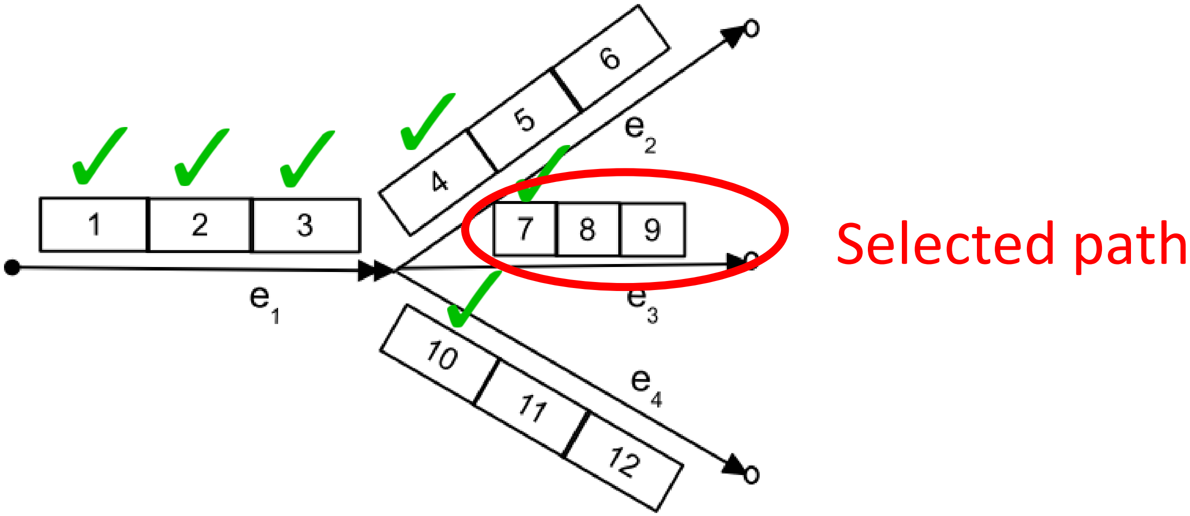

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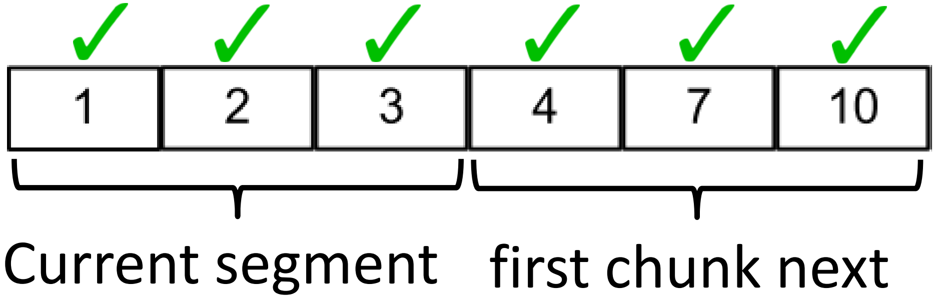

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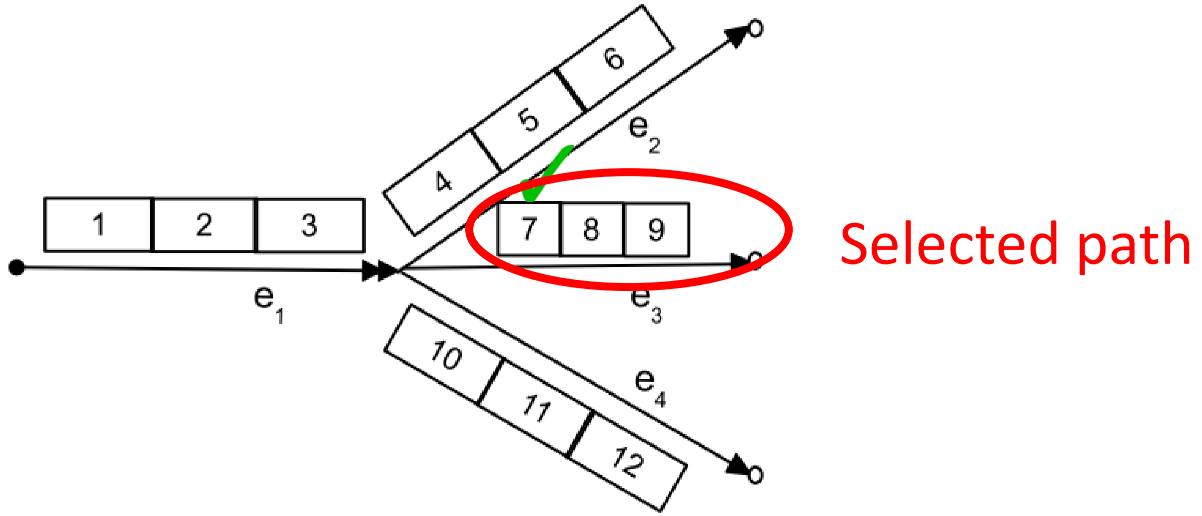

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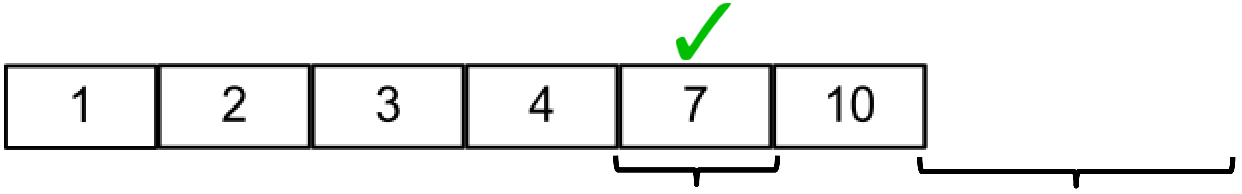

current segment

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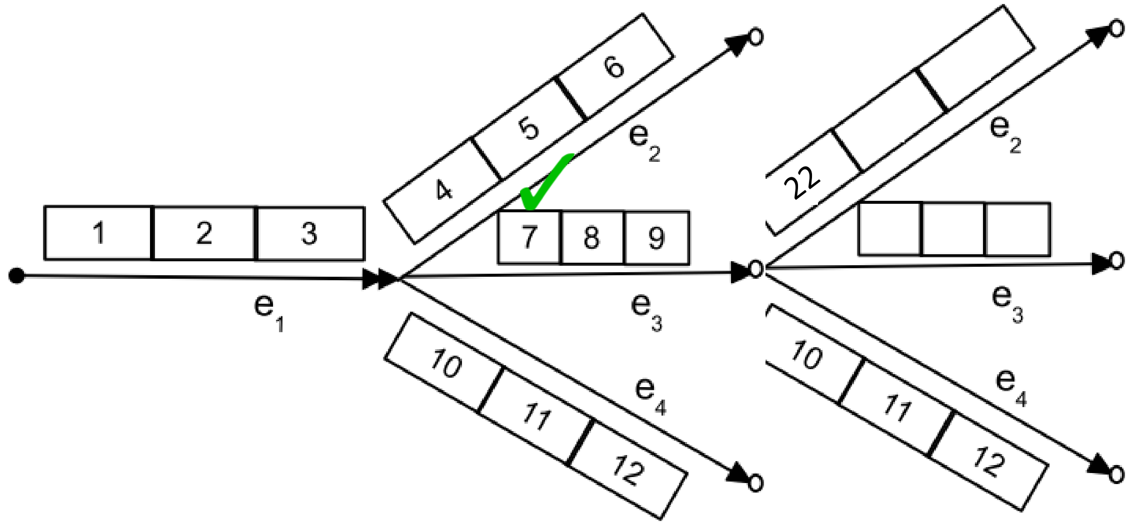

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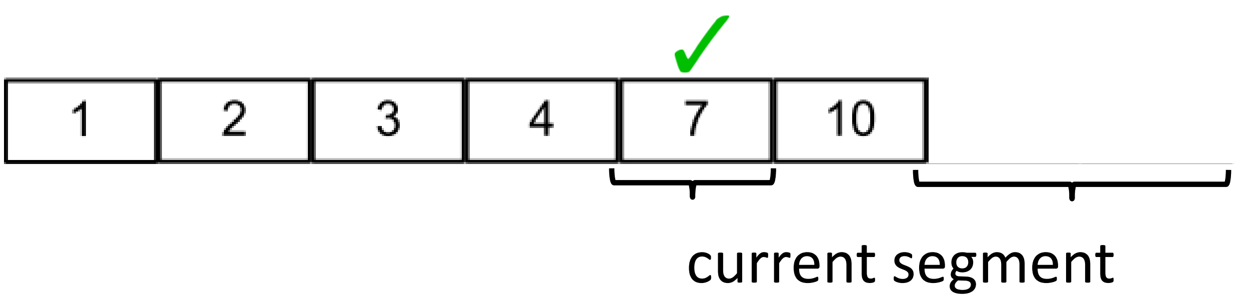

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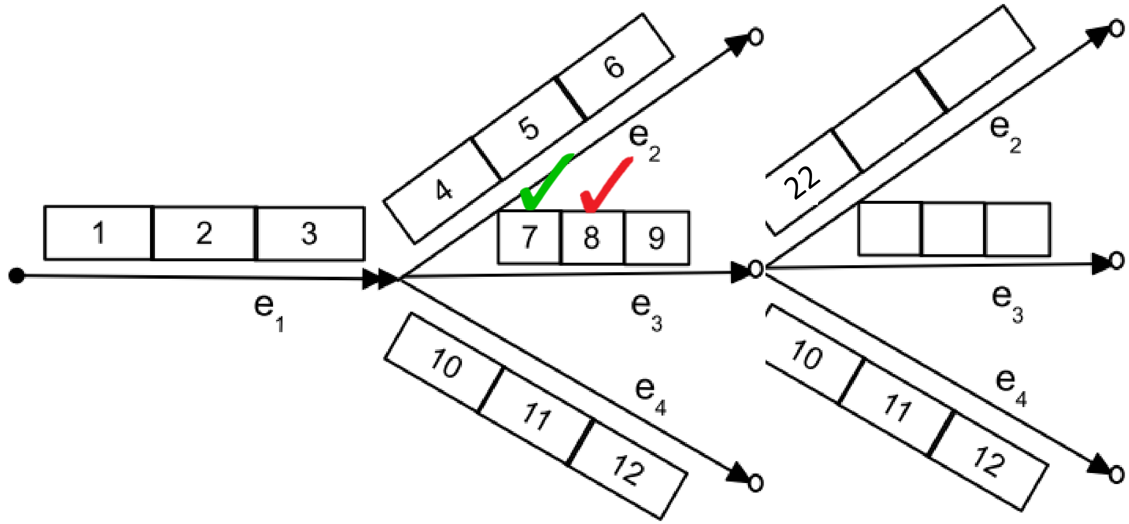

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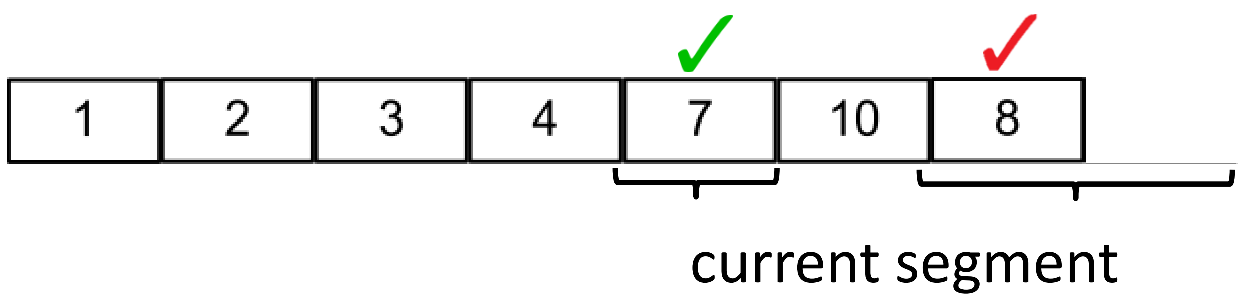

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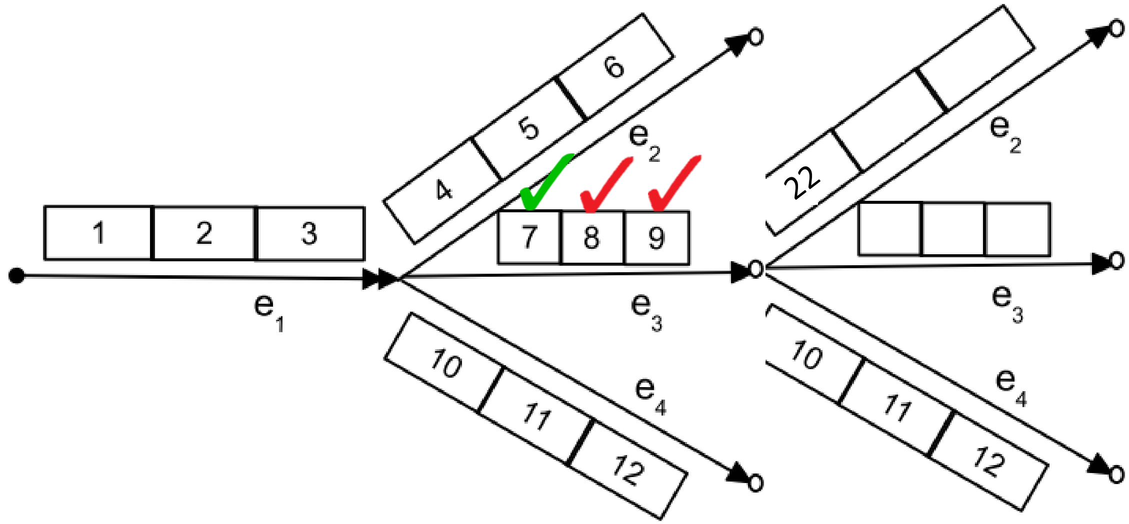

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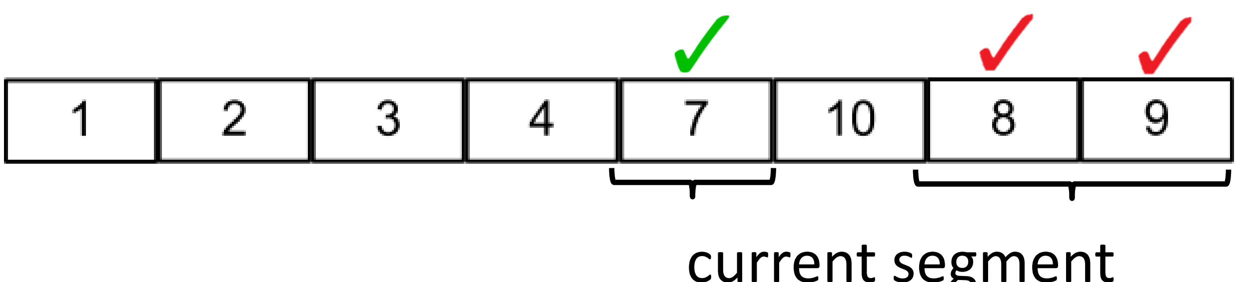

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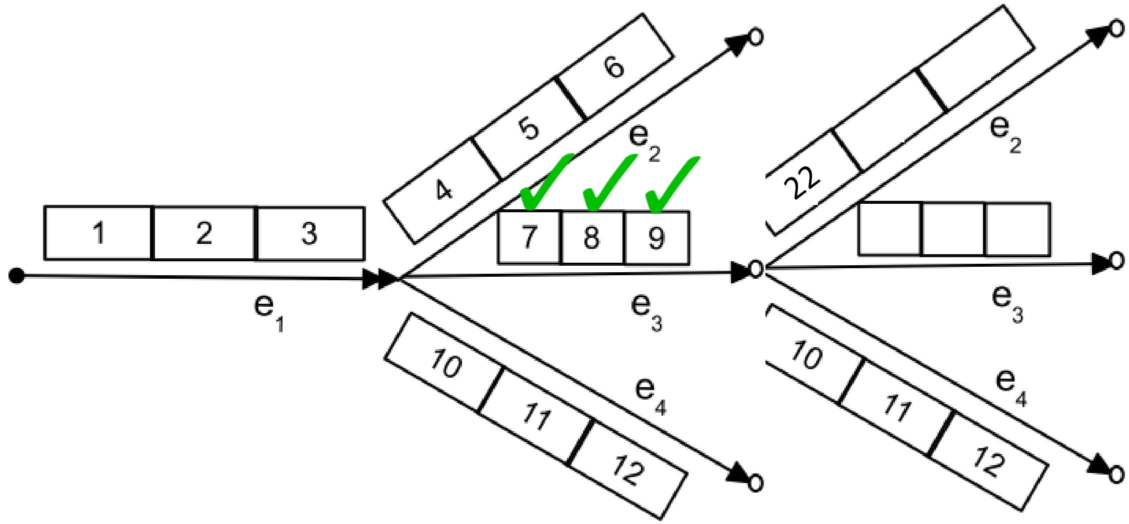

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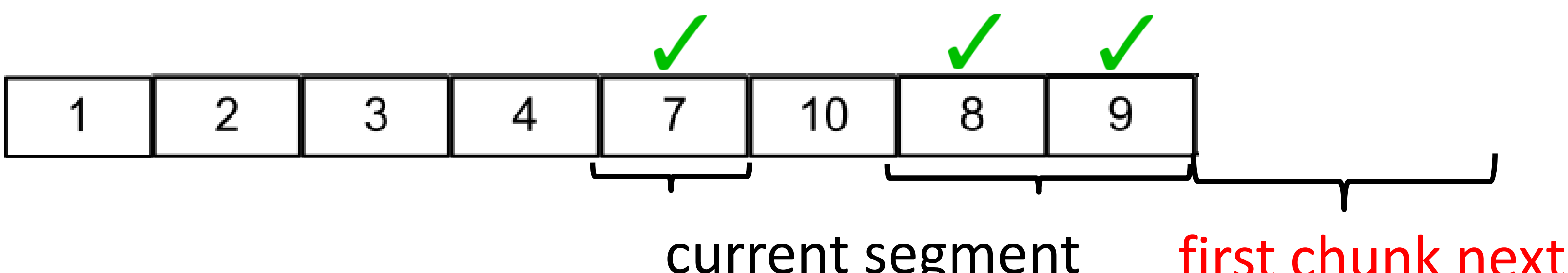

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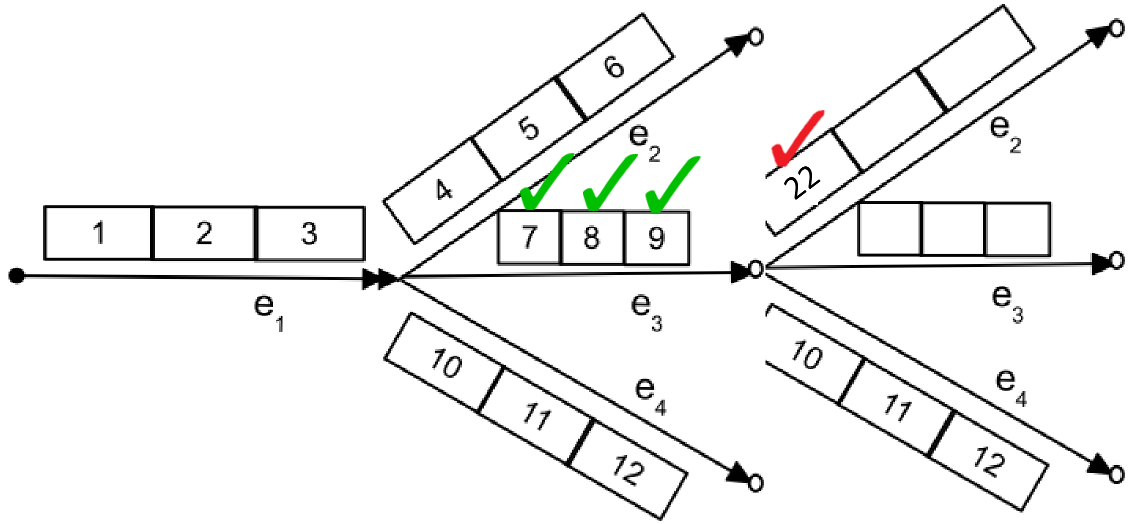

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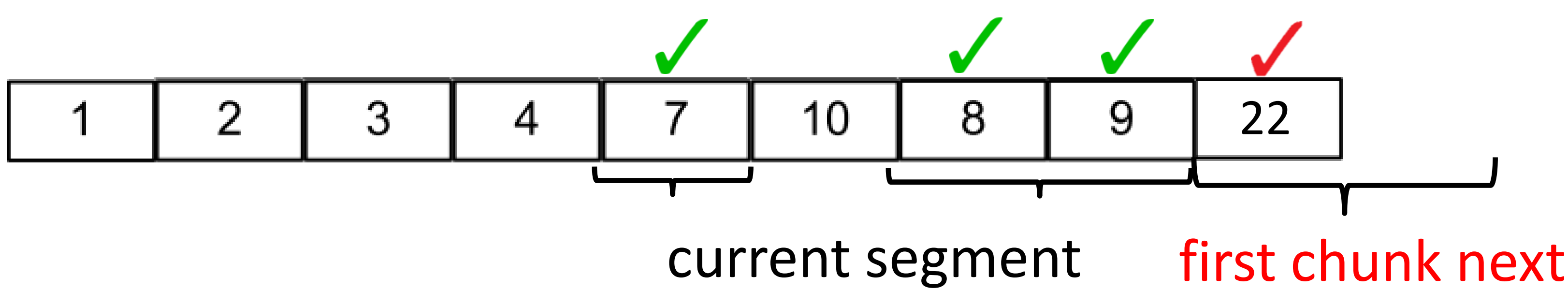
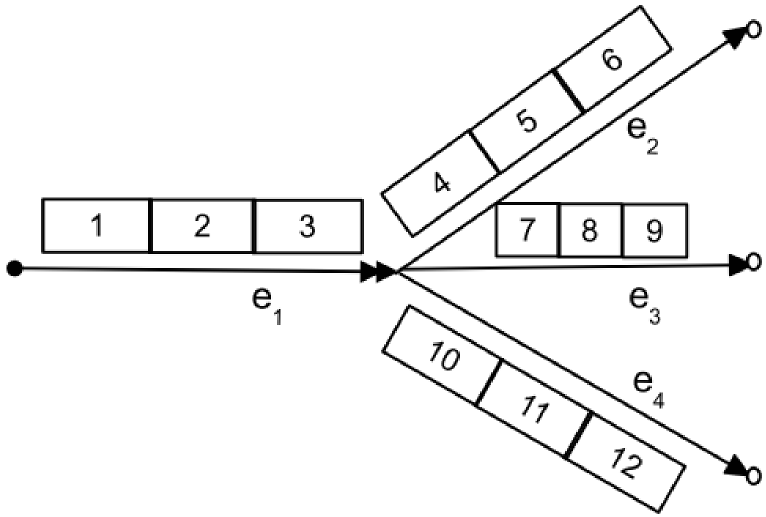


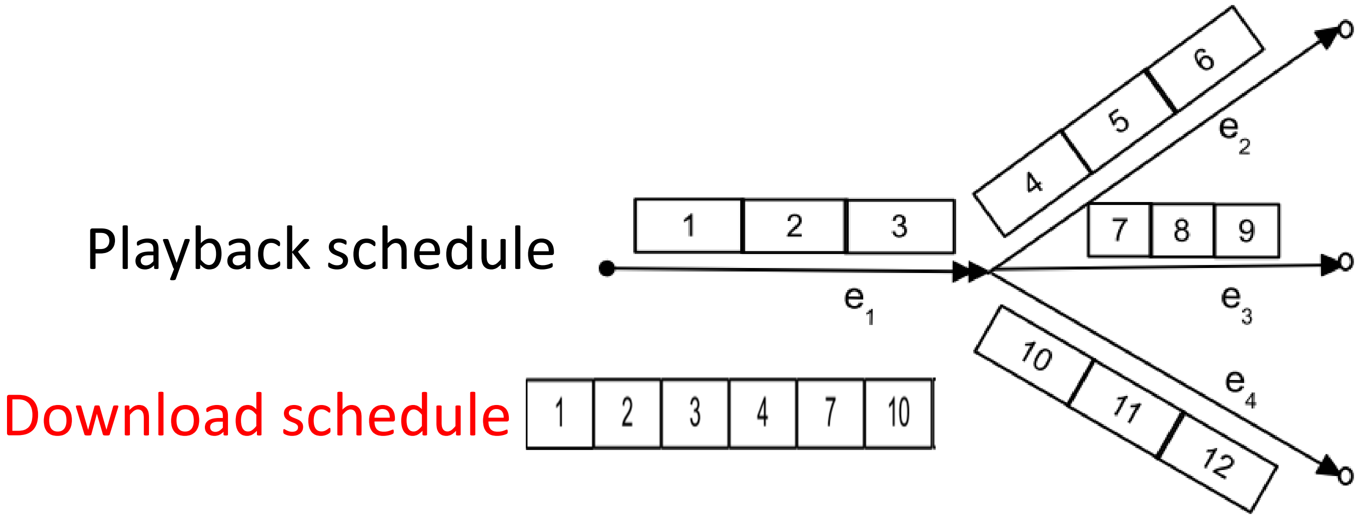
Problem Description and Constraints

Playback schedule



- Playback deadlines
  - for seamless playback without stalls

Problem Description and Constraints



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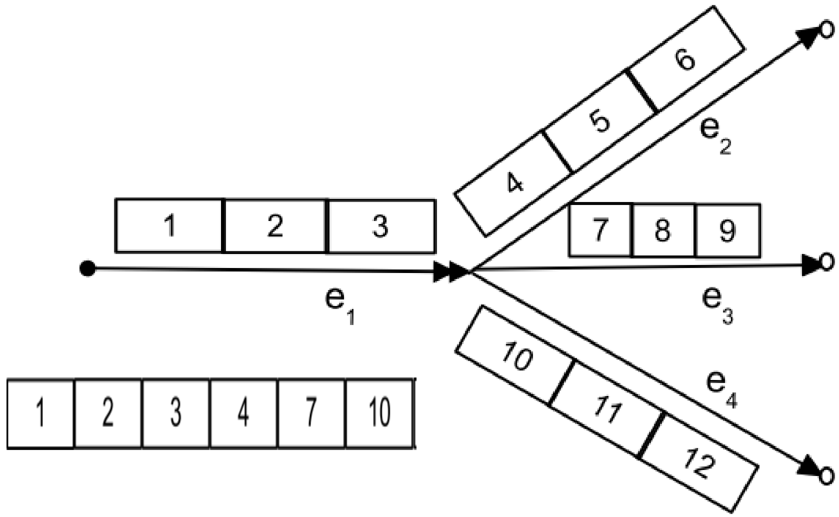

- Playback deadlines
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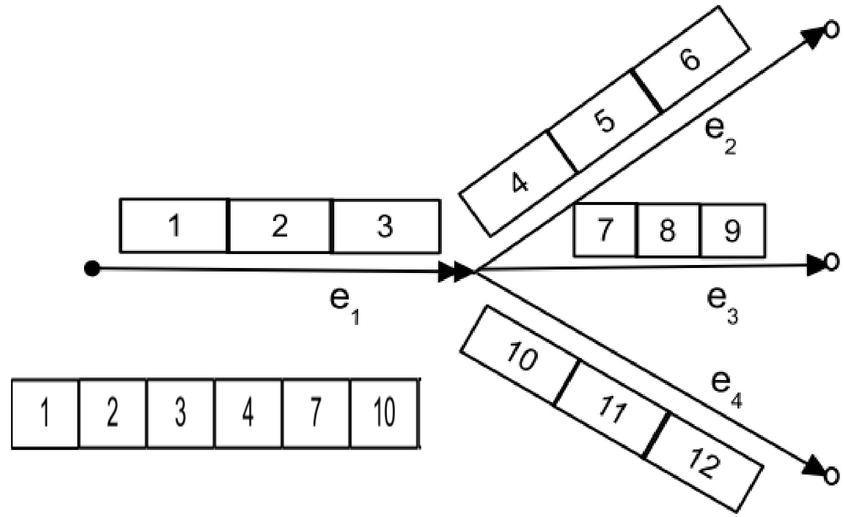
  - Current segment: e.g., 2 and 3

Problem Description and Constraints



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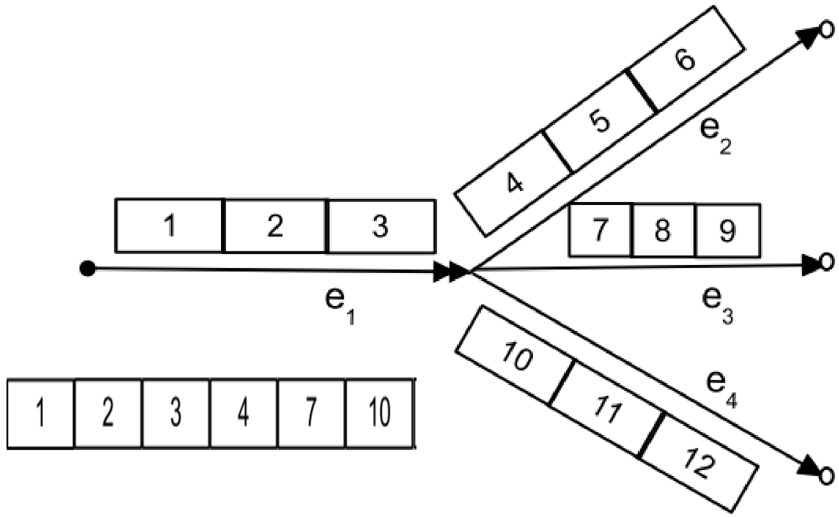
Problem Description and Constraints



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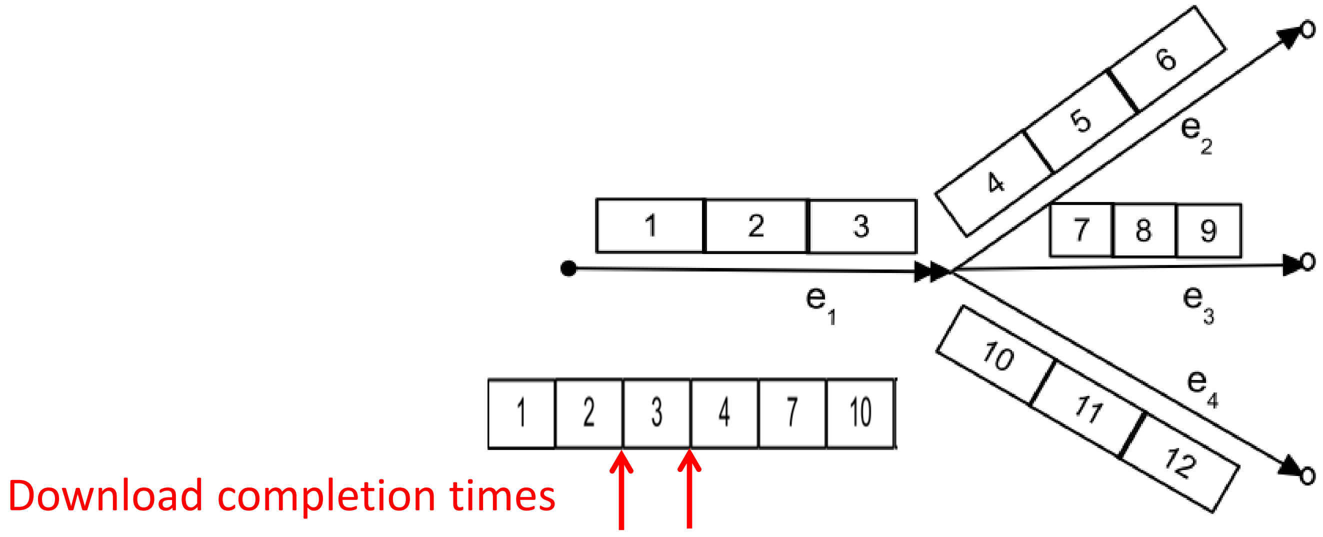
Download completion time

Problem Description and Constraints



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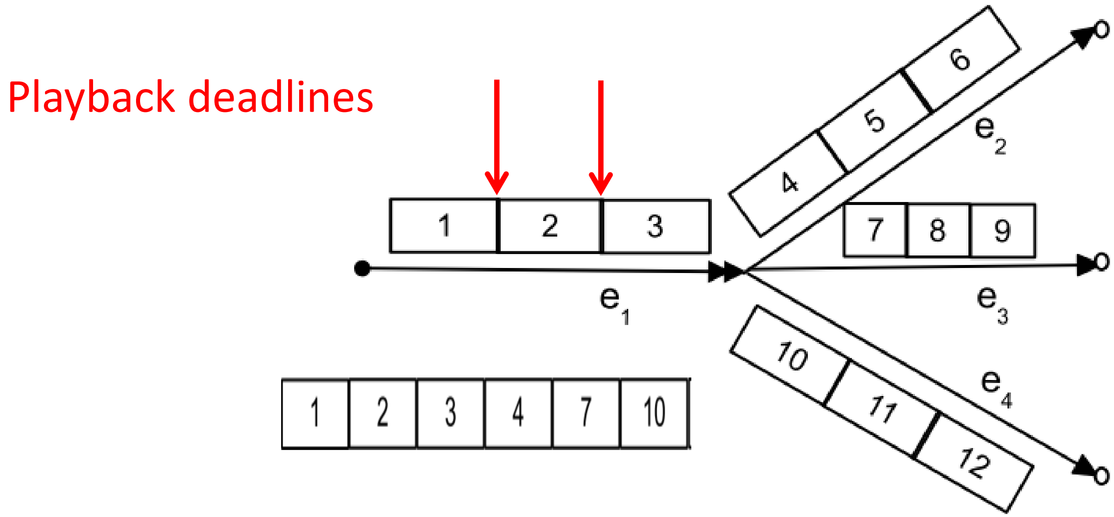

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Time of playback deadline

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Problem Description and Constraints

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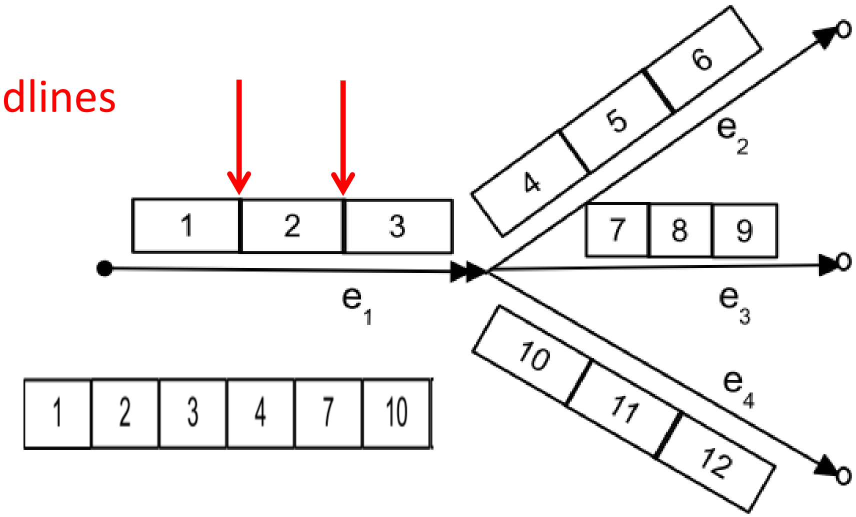

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Time of playback deadline

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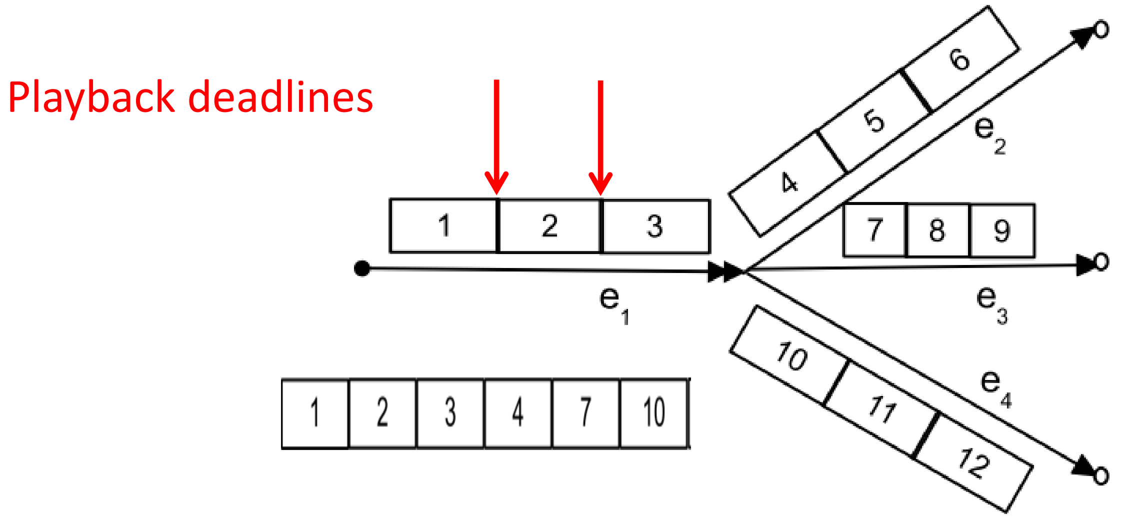

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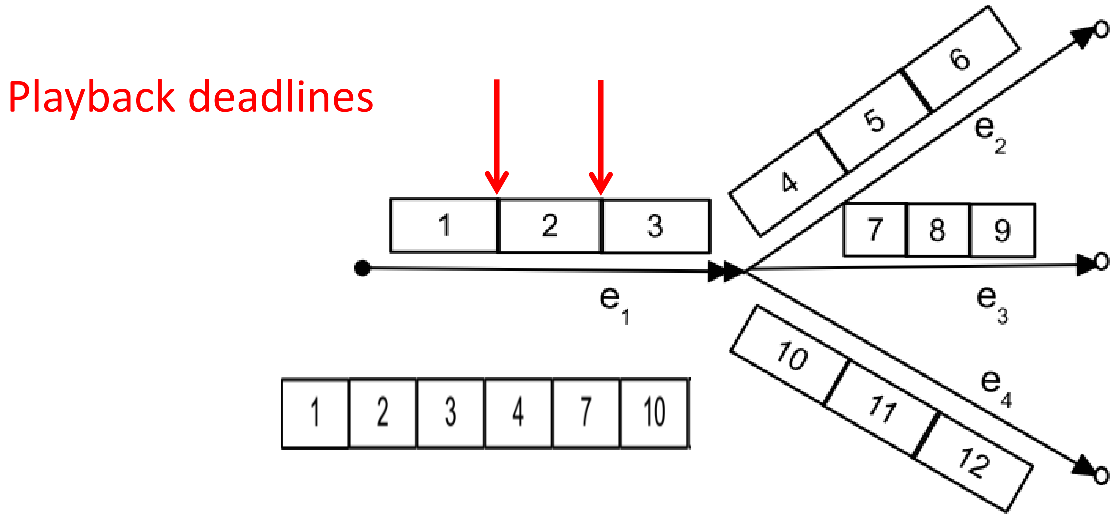
Startup delay

Problem Description and Constraints



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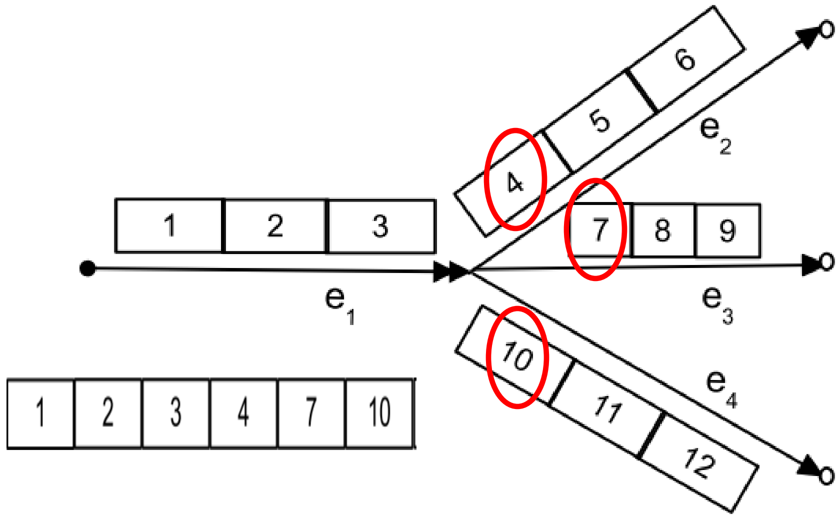
  - for seamless playback without stalls
  - Current segment: e.g., 2 and 3

$$t_i^c \le t_i^d = \tau + \sum_{j=1}^{i-1} l_j, \quad \text{if } 1 \le i \le n_e$$

Startup delay

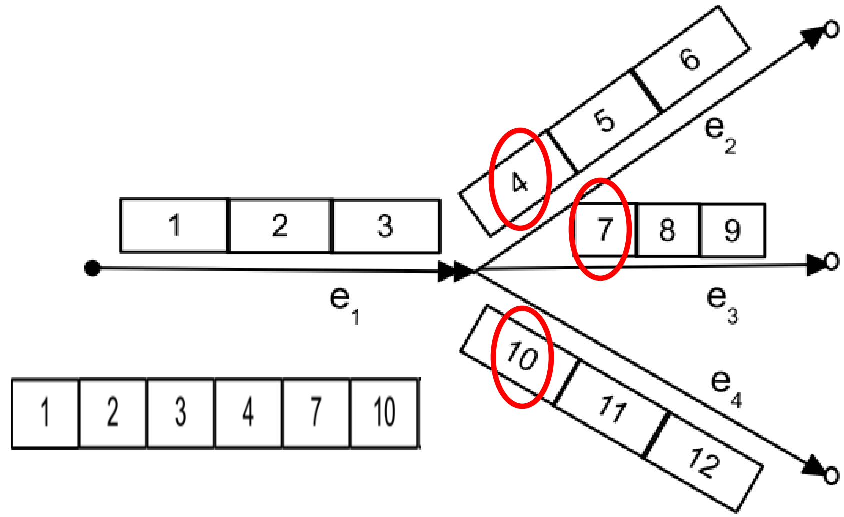
Playtime of earlier chunks

Problem Description and Constraints



- Playback deadlines
  - for seamless playback without stalls
  - First chunks next segment: e.g., 4, 7, and 10

Problem Description and Constraints



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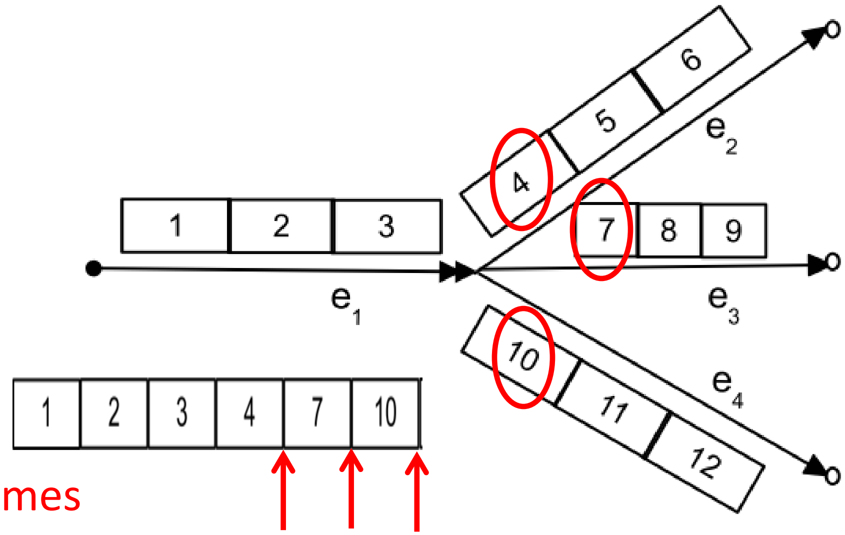

Download completion times

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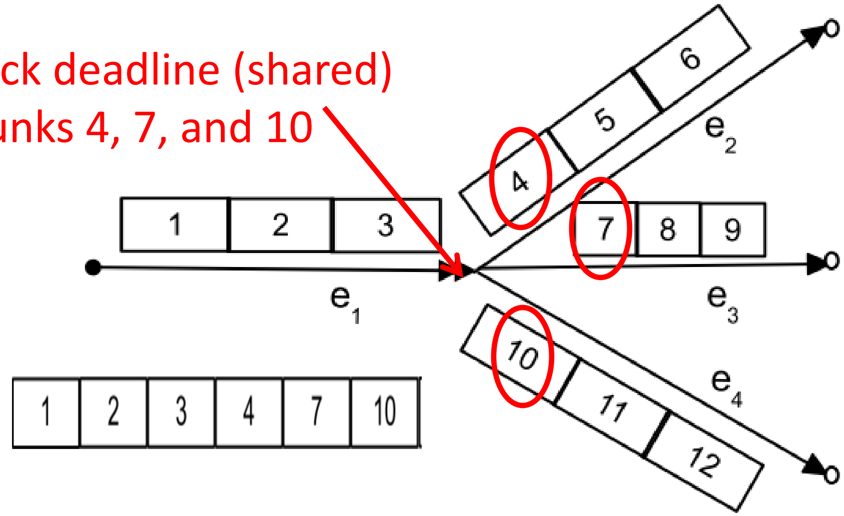
Download completion times

Problem Description and Constraints

Playback deadline (shared) for chunks 4, 7, and 10



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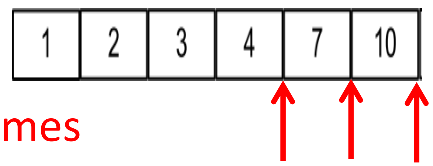
$$t_i^c \le t_i^d = \tau + \sum_{j=1}^{n_e} l_j, \quad \text{if } n_e < i \le n_e + |\mathcal{E}^b|$$

Time at which branch point is reached

Download completion times

Problem Description and Constraints



Download completion times

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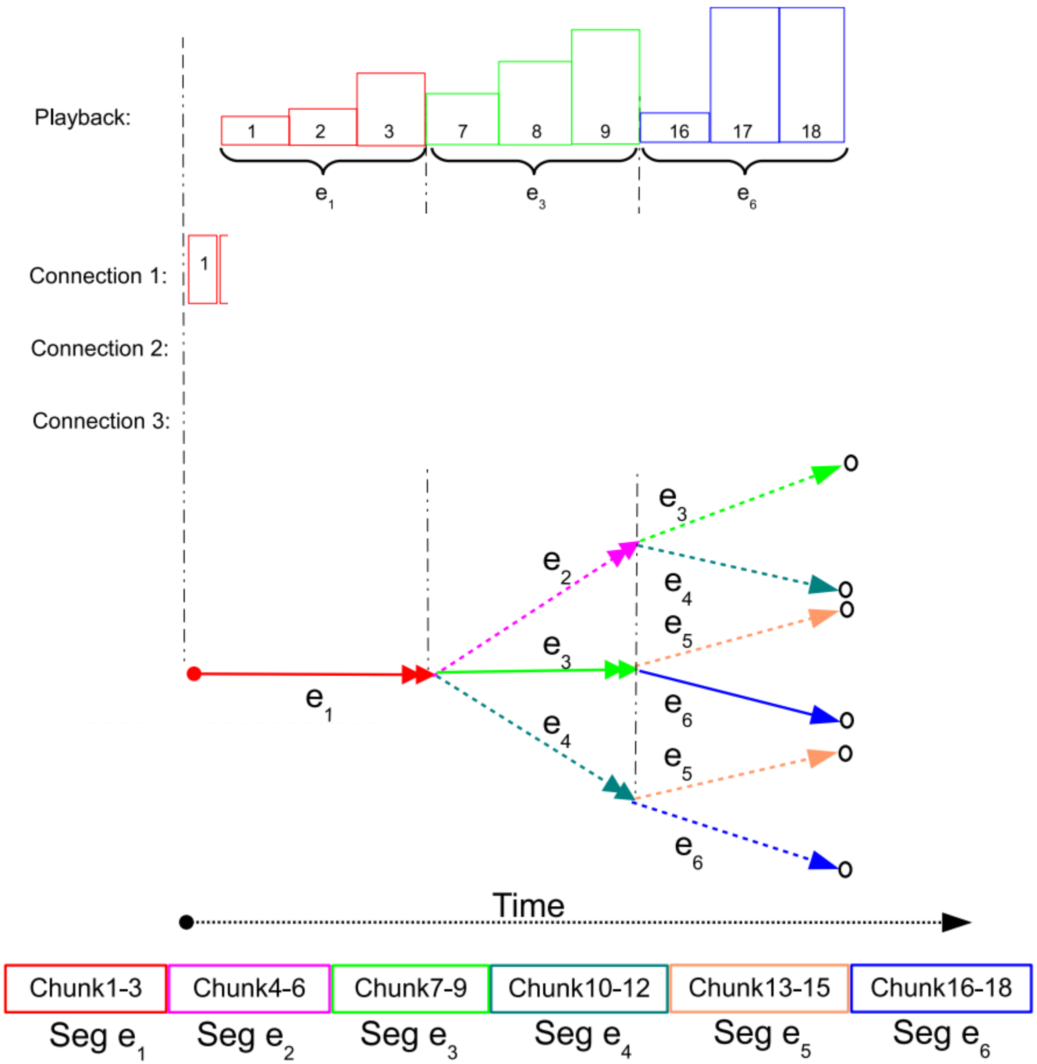
Concurrent Download Example



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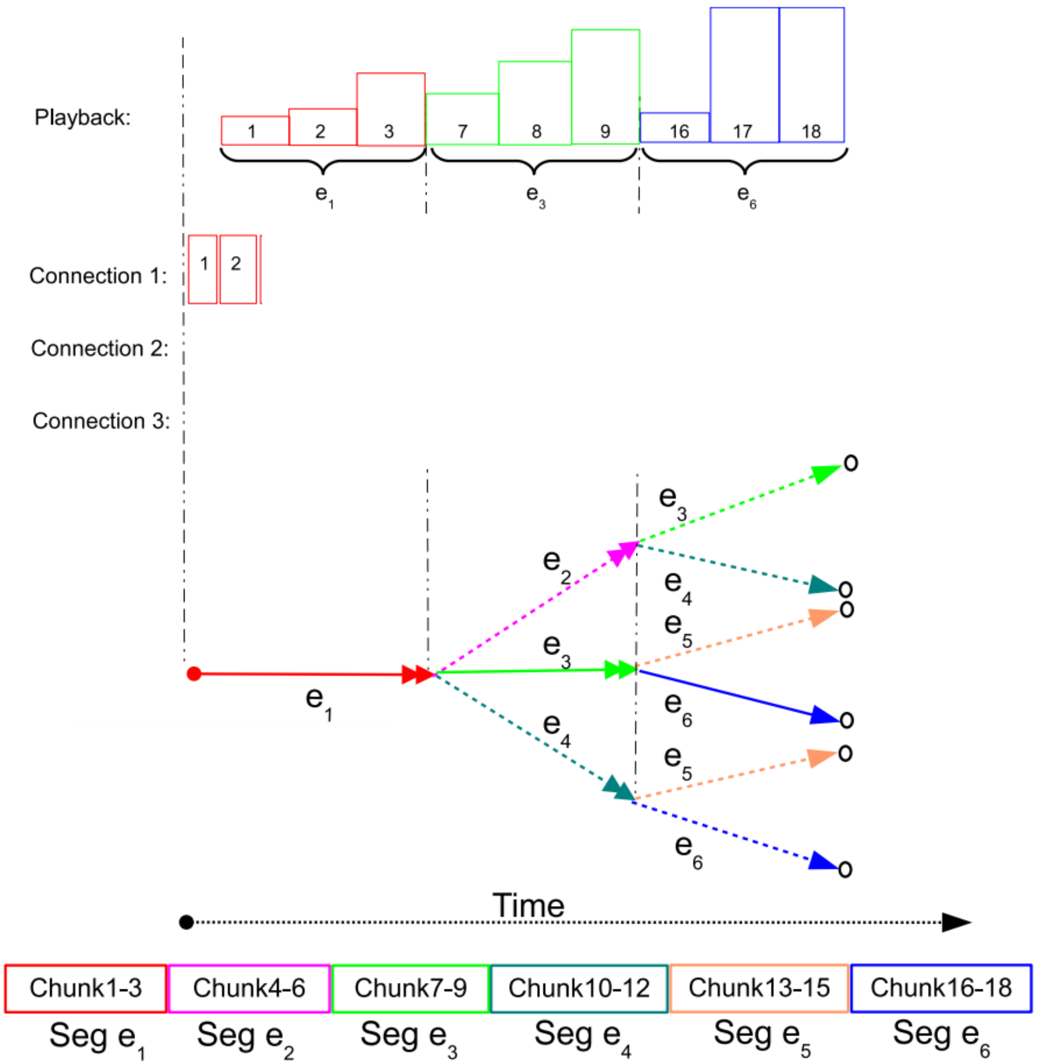

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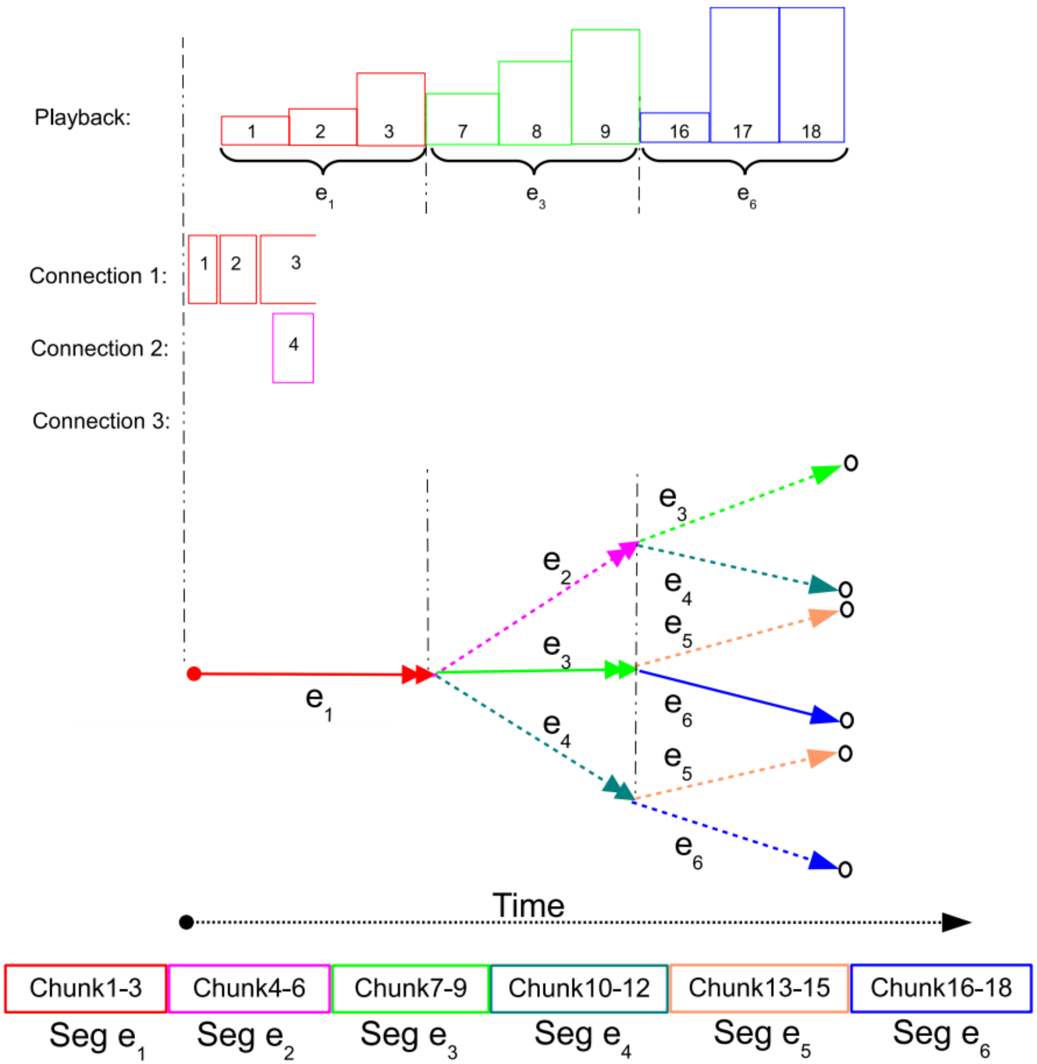

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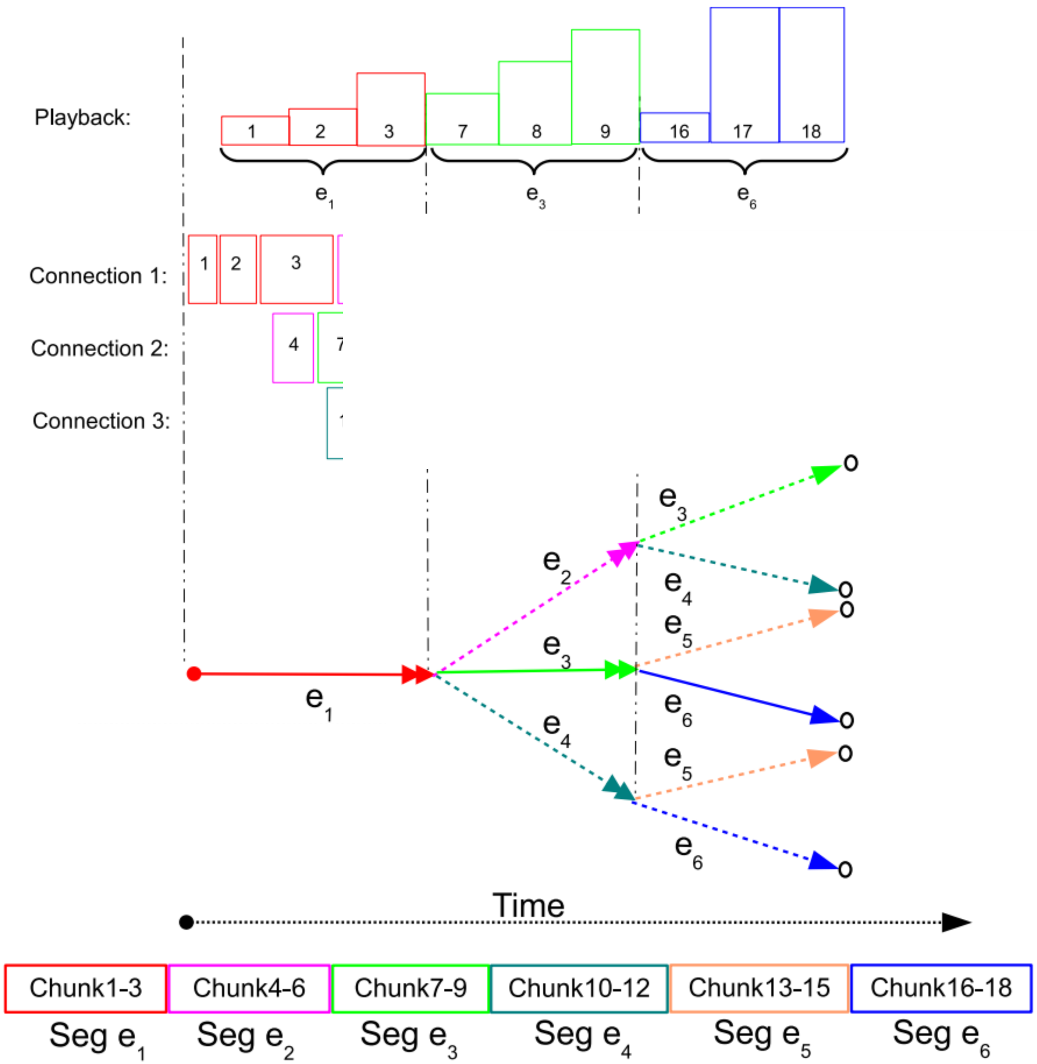

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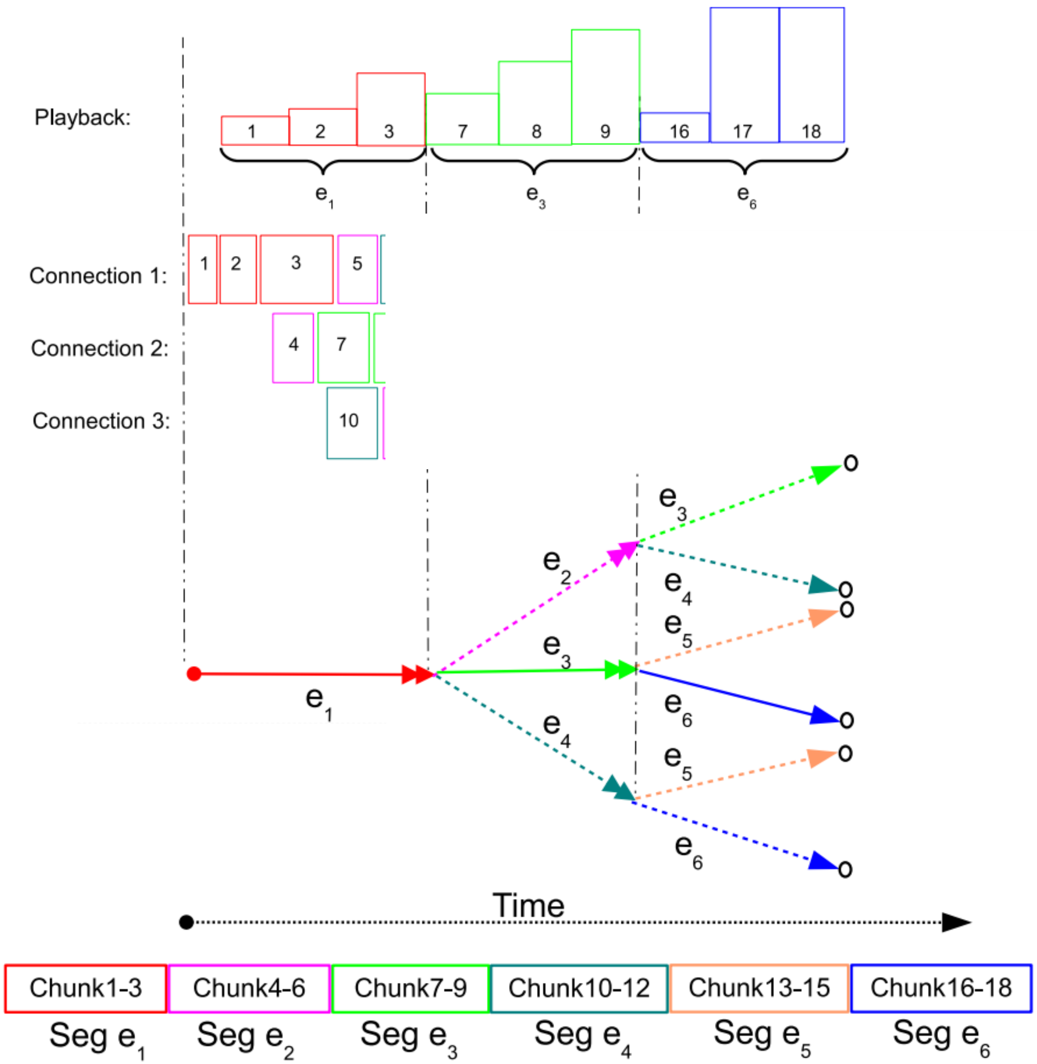

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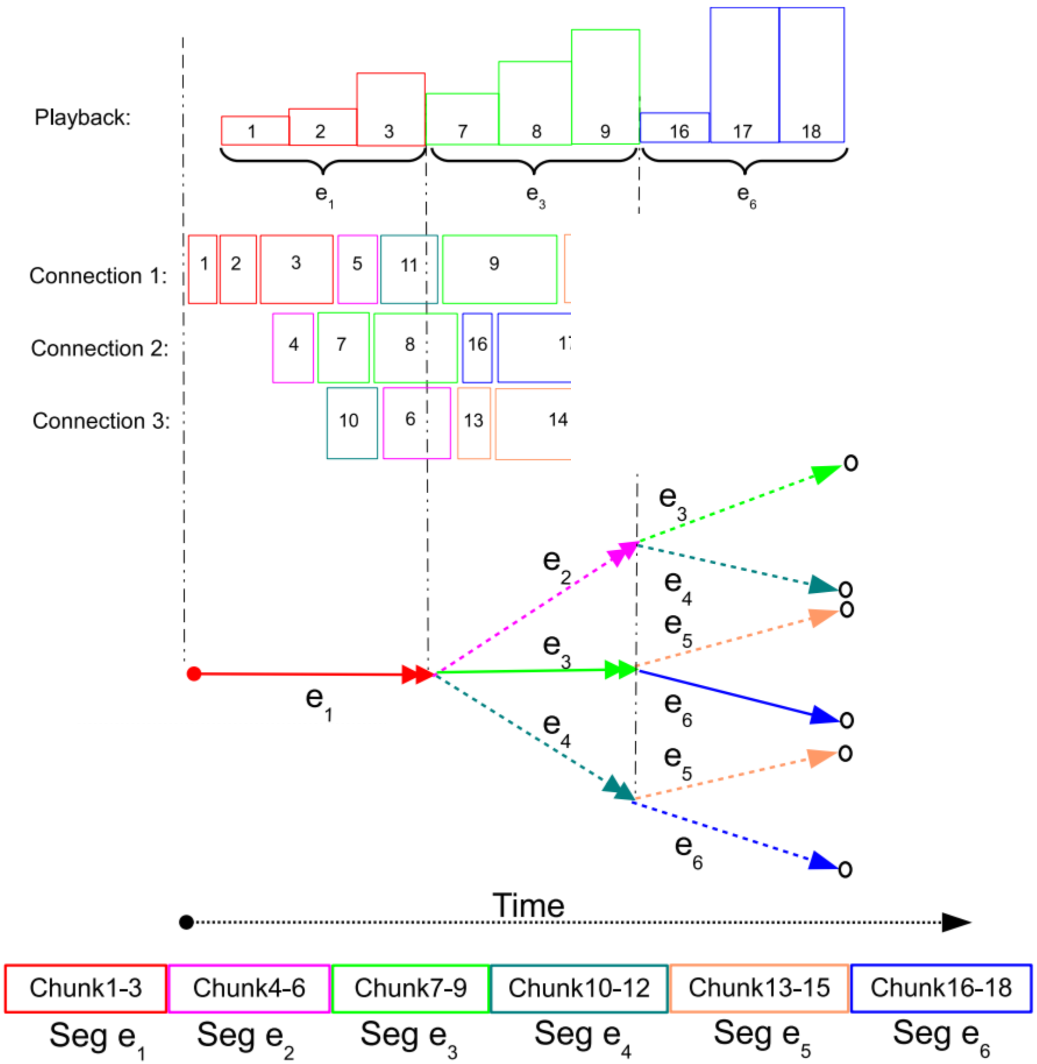

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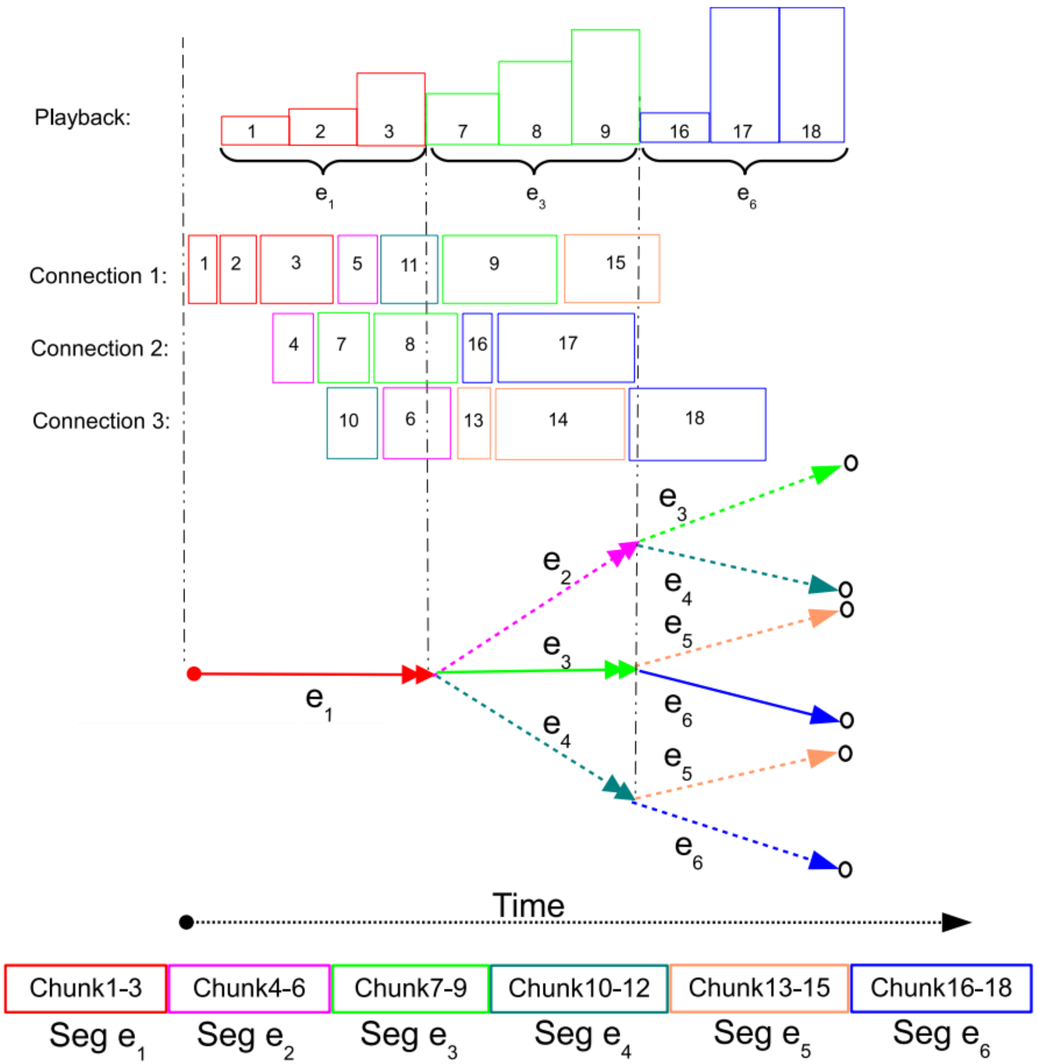

Prefetching Policies

- At download completion
  - Decide number of chunks to download next
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- Exponential number of candidate schedules
- Our optimized policies restrict the number of candidate schedules to consider
  - Policies differ in number of candidate schedules and how aggressive they are (in choosing qualities)

Comparison Between Policies

Policy	Connections	Schedules considered	Objective
All schedules	$1 \le c_i \le C^{max}$	Q^M, where $M=n_e+\|\xi_b\|-m$	-
Optimized non-increasing quality	$1 \le c_i \le C^{max}$	$\binom{M+Q-1}{Q-1}$	$\sum_{i=1}^{n_e} q_i l_i + \sum_{i=n_e+1}^{n_e+\|\xi_b\|} q_i l_i$
Optimized maintainable quality	$1 \le c_i \le C^{max}$	Q	$\sum_{i=1}^{n_e} q_i l_i + \sum_{i=n_e+1}^{n_e+\|\xi_b\|} q_i l_i$

- Total number of schedules: Q^M
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Single connection	1	Q	$\sum_{i=1}^{n_e} q_i l_i + \sum_{i=n_e+1}^{n_e+\lvert\xi_b\rvert} q_i l_i$
Greedy bandwidth	$1 \le c_i \le C^{max}$		$\sum_{i=j}^{j+m} q_i l_i$

- Single connection: baseline comparing to policies which do not use multiple connections
- Greedy bandwidth: bandwidth aggressive as opposed to aggressive quality choices
- Naïve: benchmark to regular branched video players

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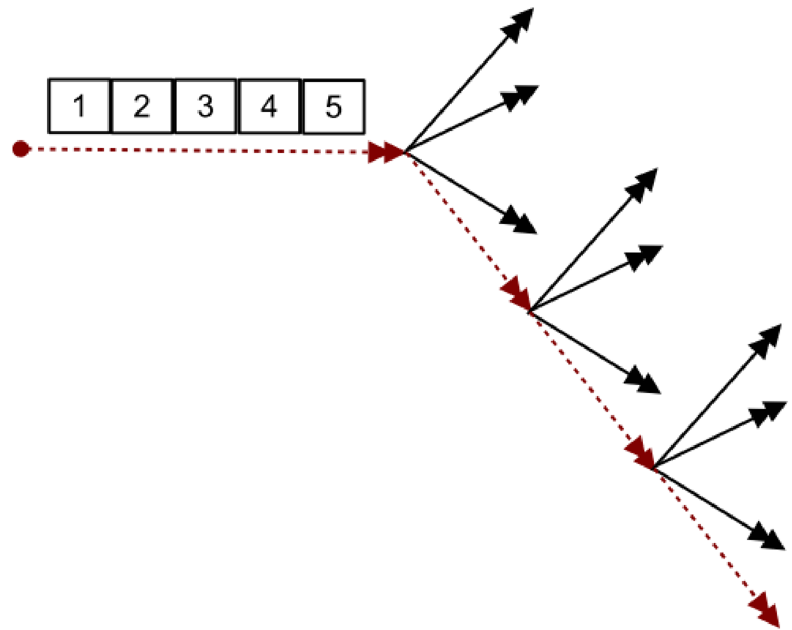

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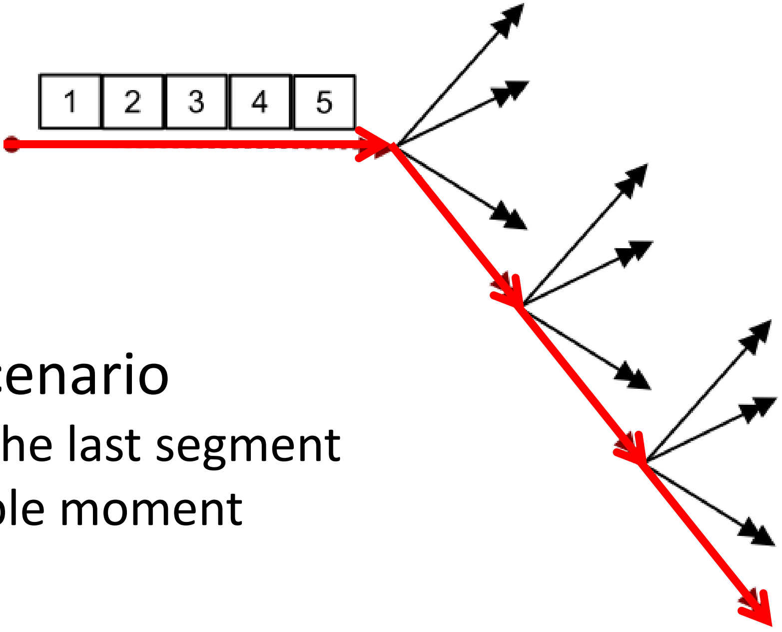

Worst case scenario

- always pick the last segment
- at last possible moment

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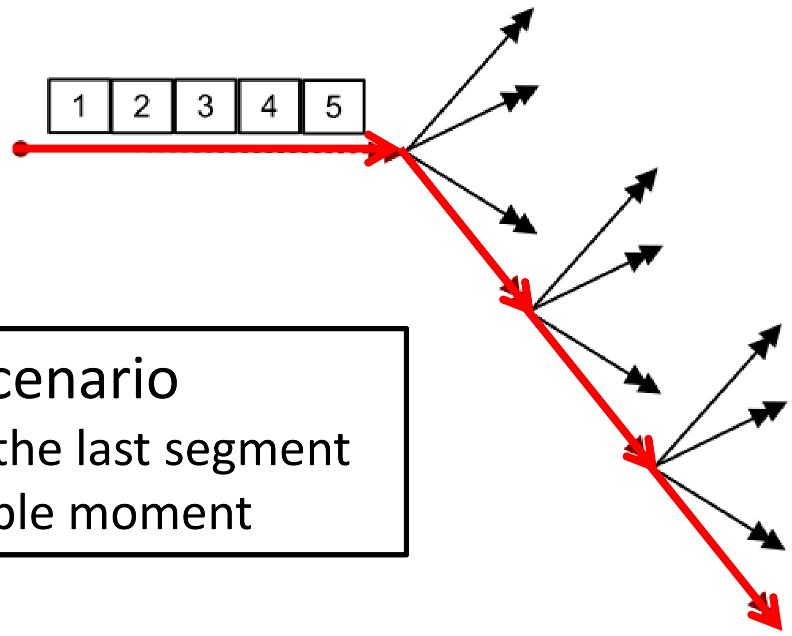

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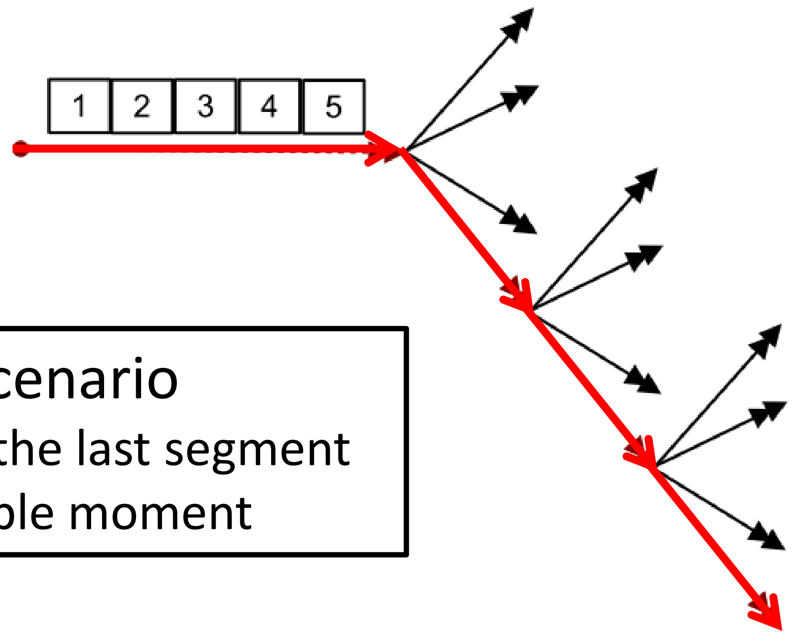

Worst case scenario
- always pick the last segment
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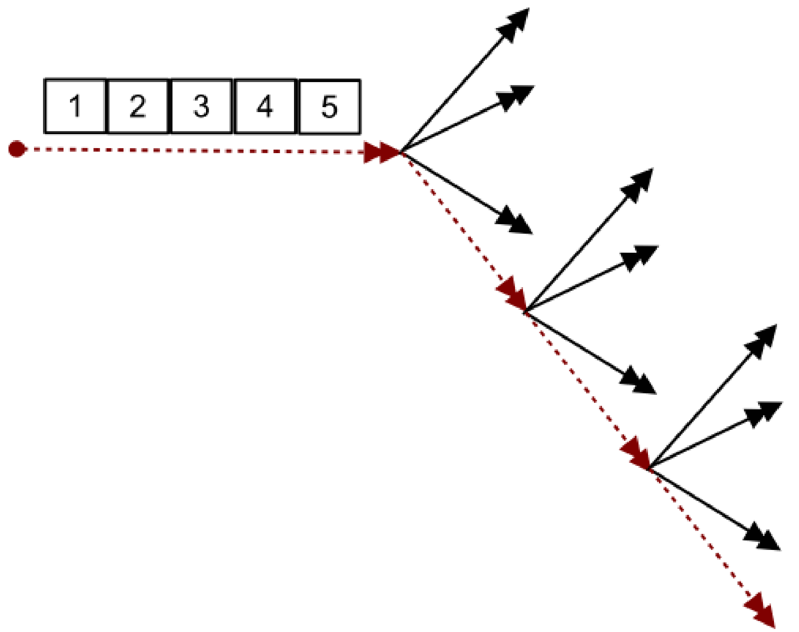
- Default scenario:
  - Chunks per segment: 5
  - Branches per branch point: 4
  - Branch points: 3

Test Scenario



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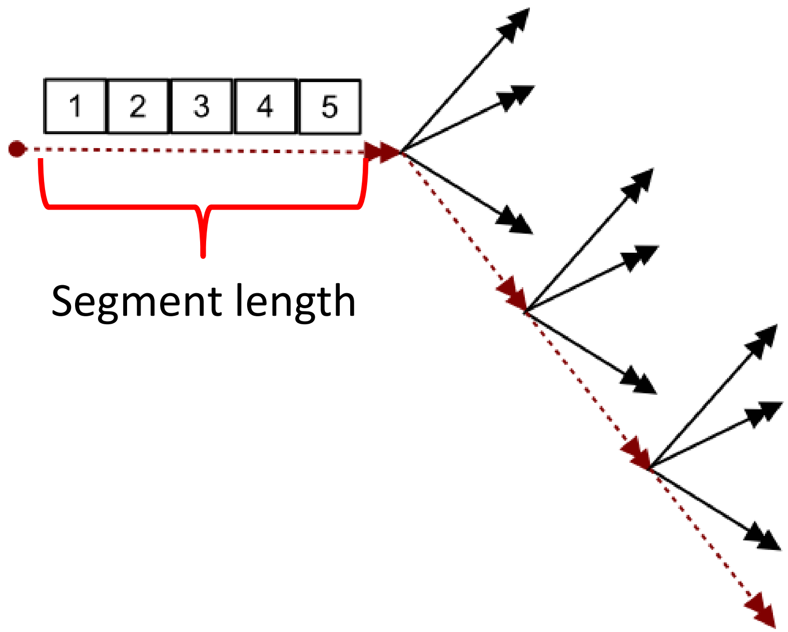

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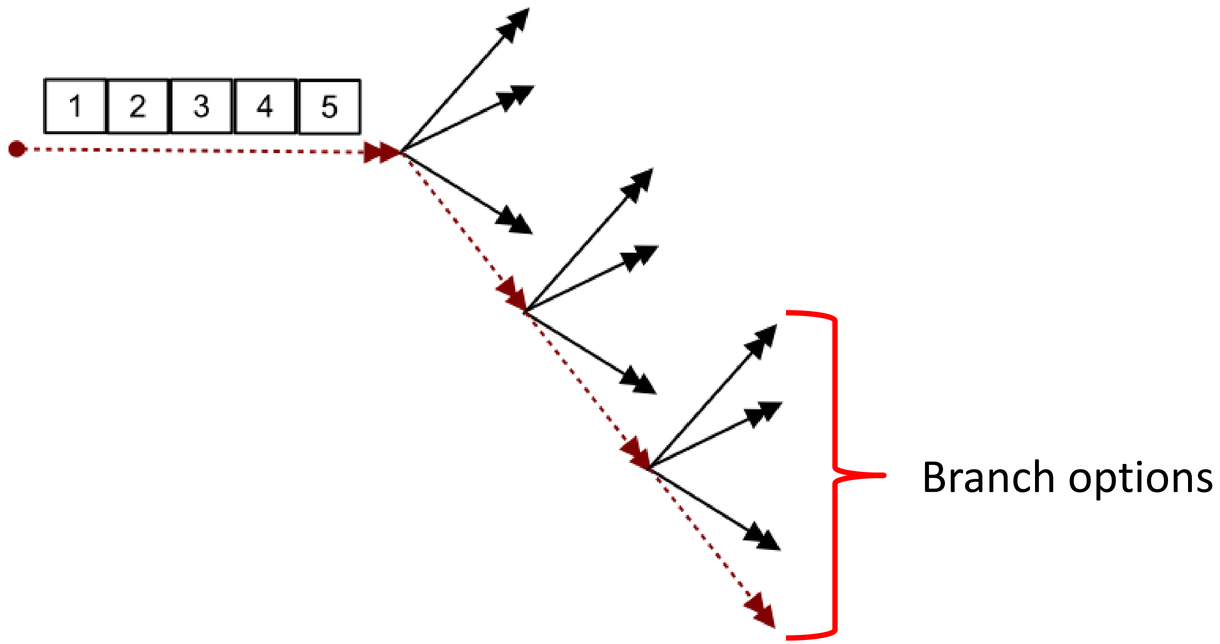

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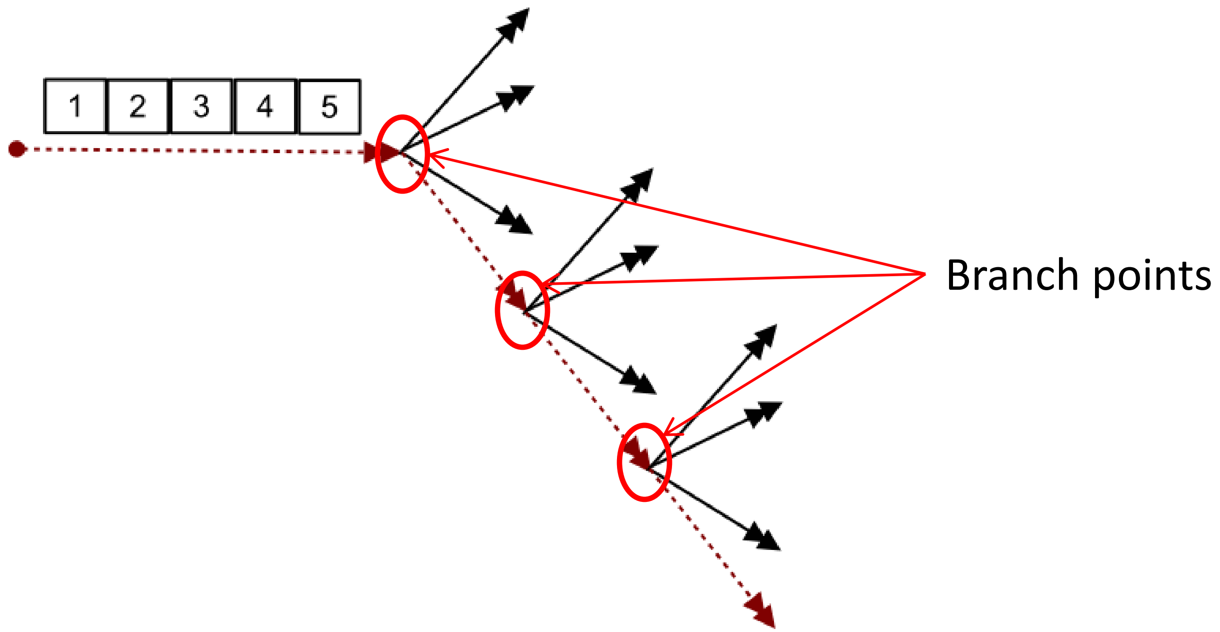

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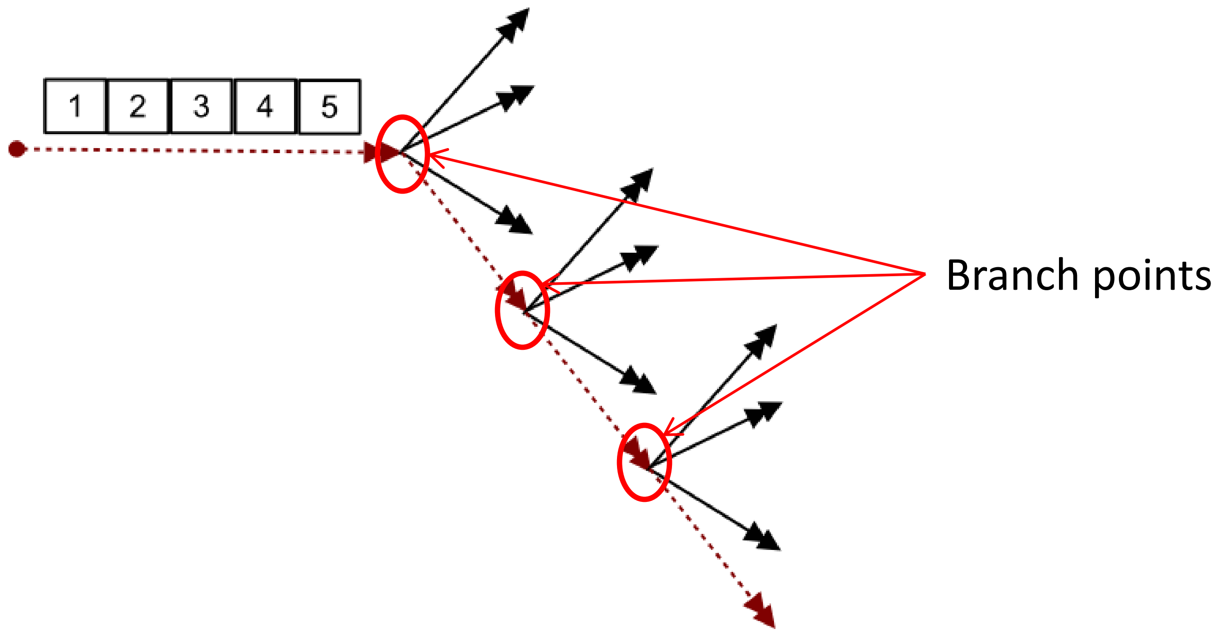

- Default scenario:
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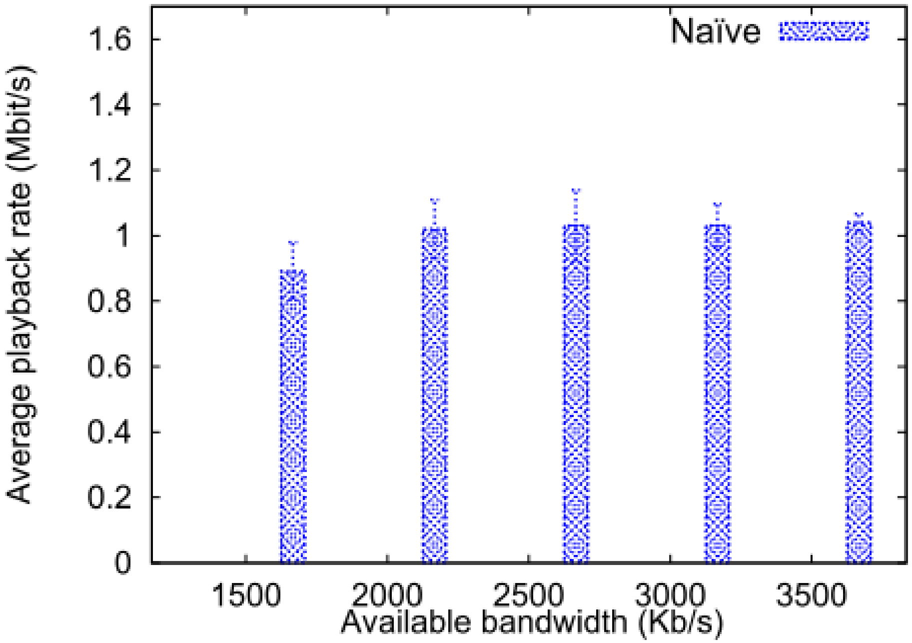
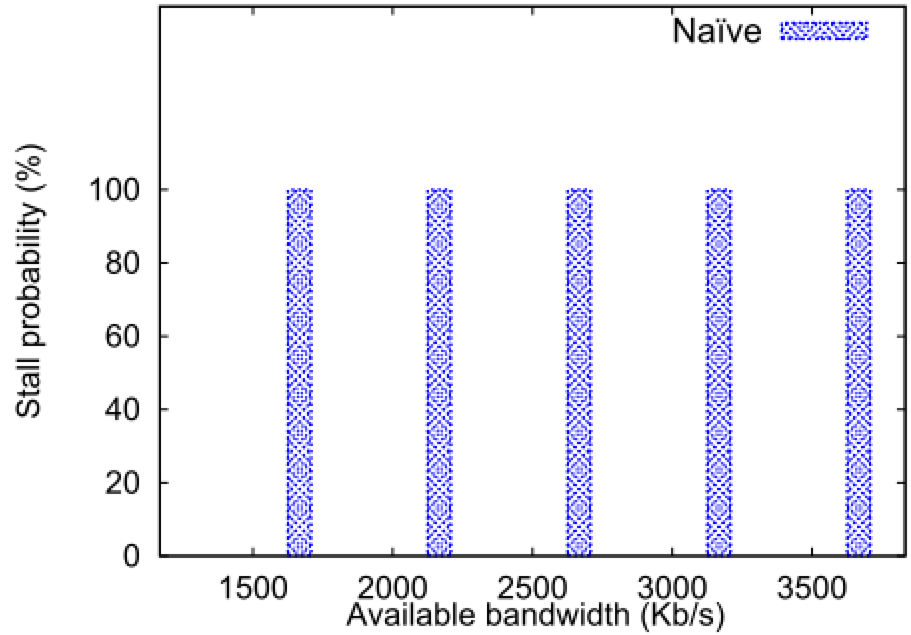
- Results are averages over 30 experiments

Policy Comparison





- Naïve policy: does not perform prefetching
  - Stalls at every branch point
  - Note: High playback rate is misleading on its own

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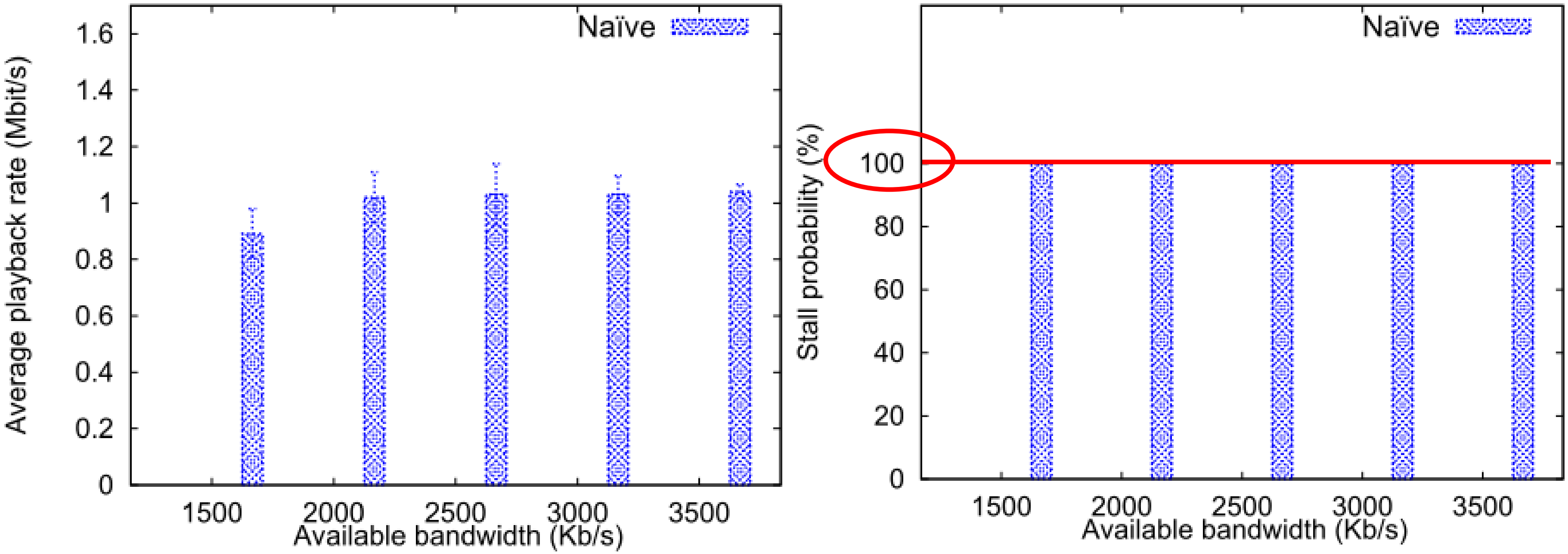

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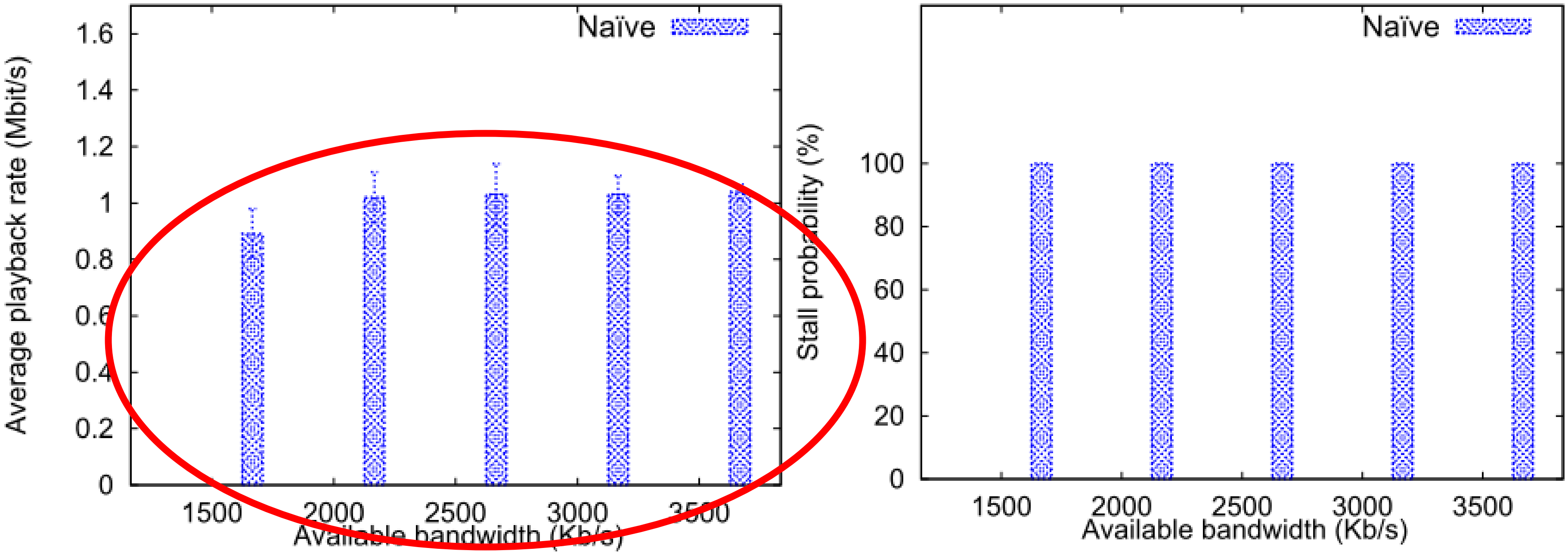

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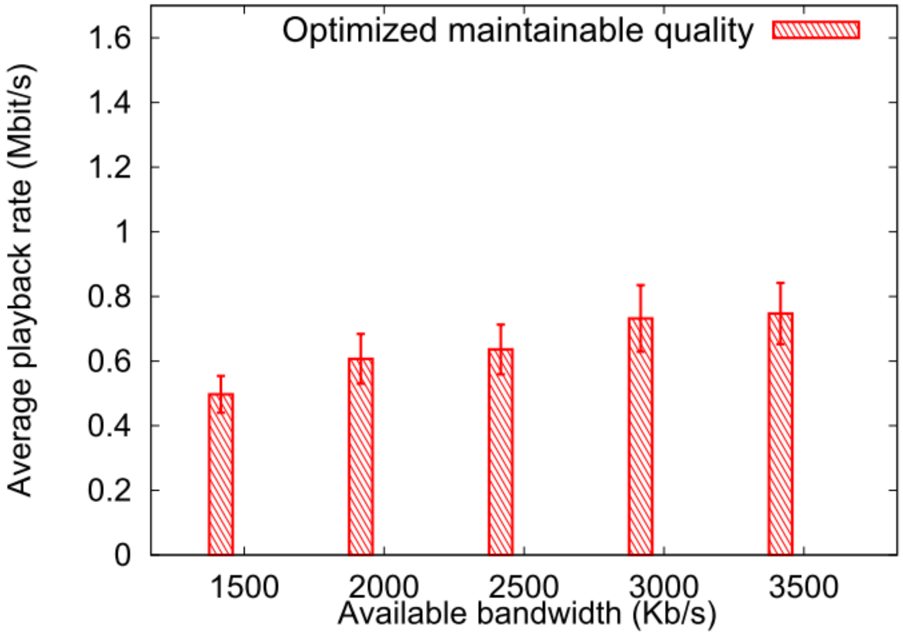

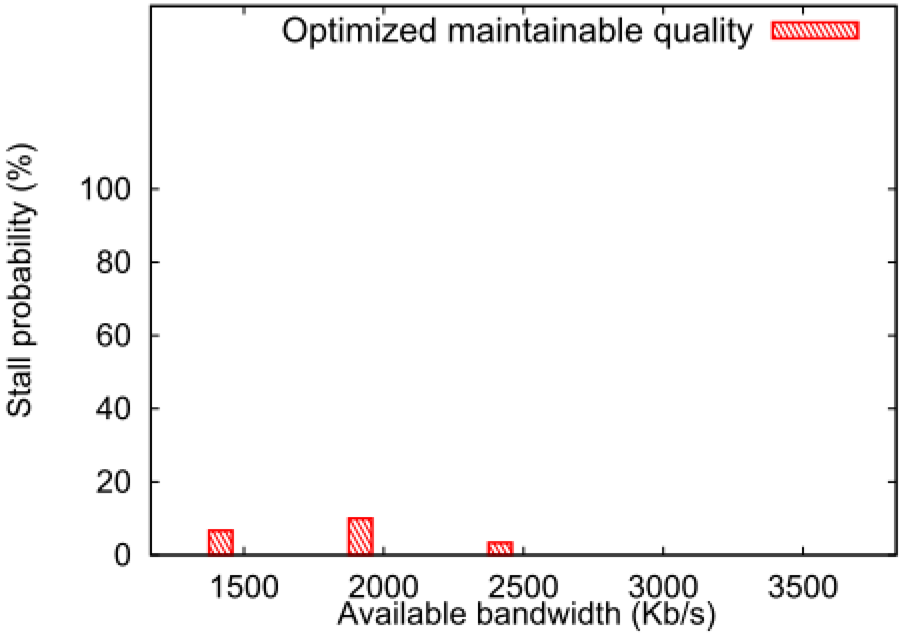

- *Optimized maintainable quality* provides best tradeoff

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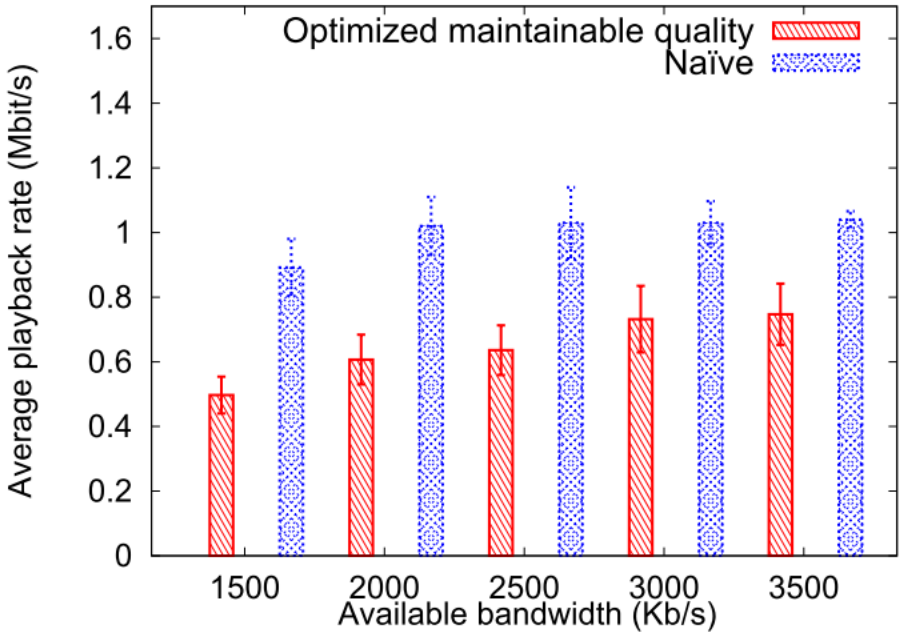

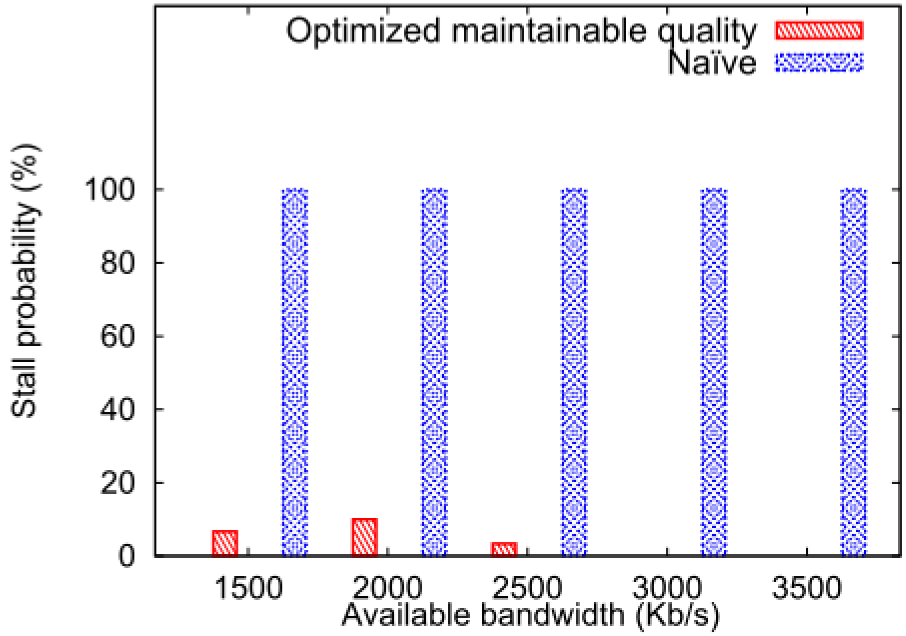

- *Optimized maintainable quality* provides best tradeoff
  - Much lower stall probability
  - Tradeoff is somewhat lower playback rate

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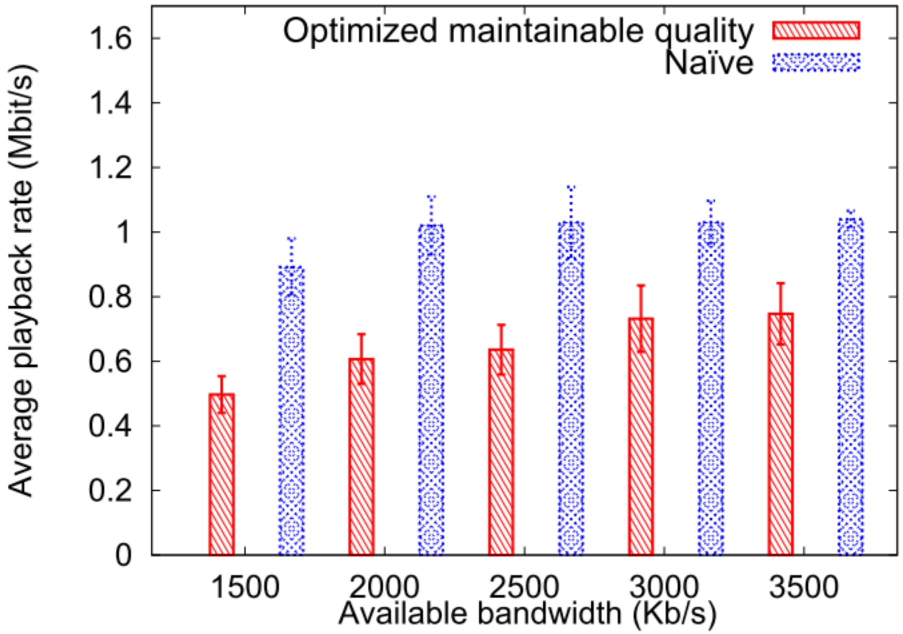

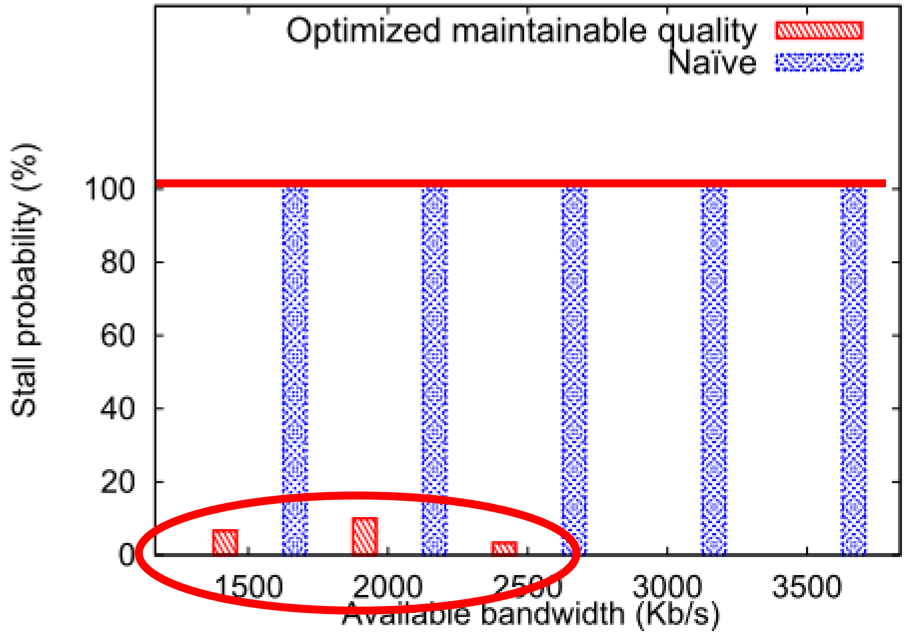

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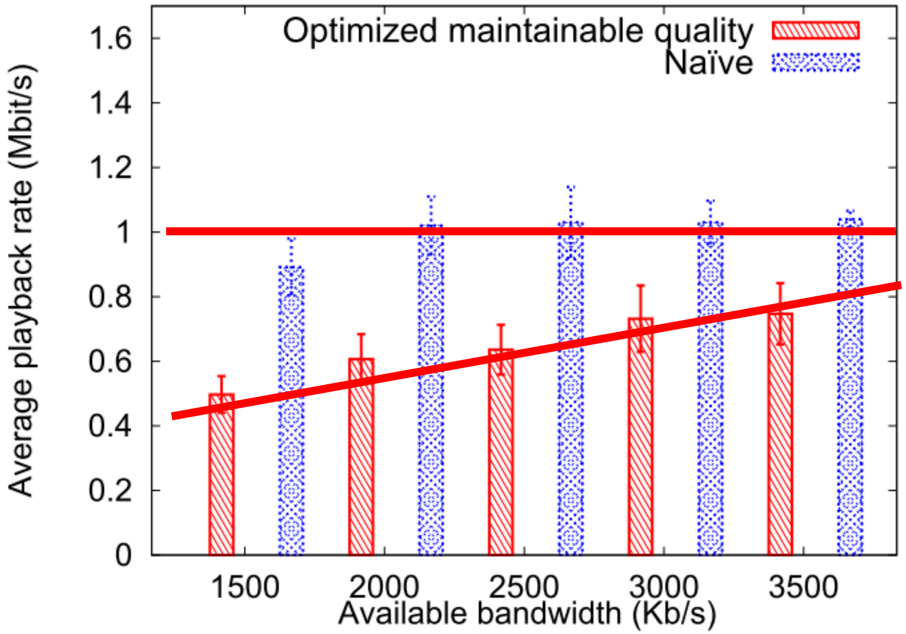

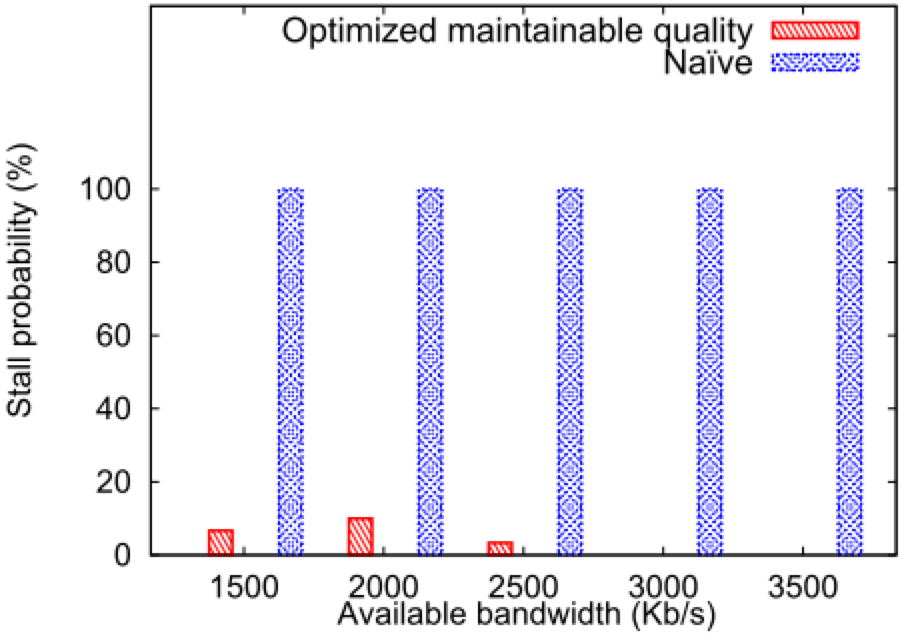

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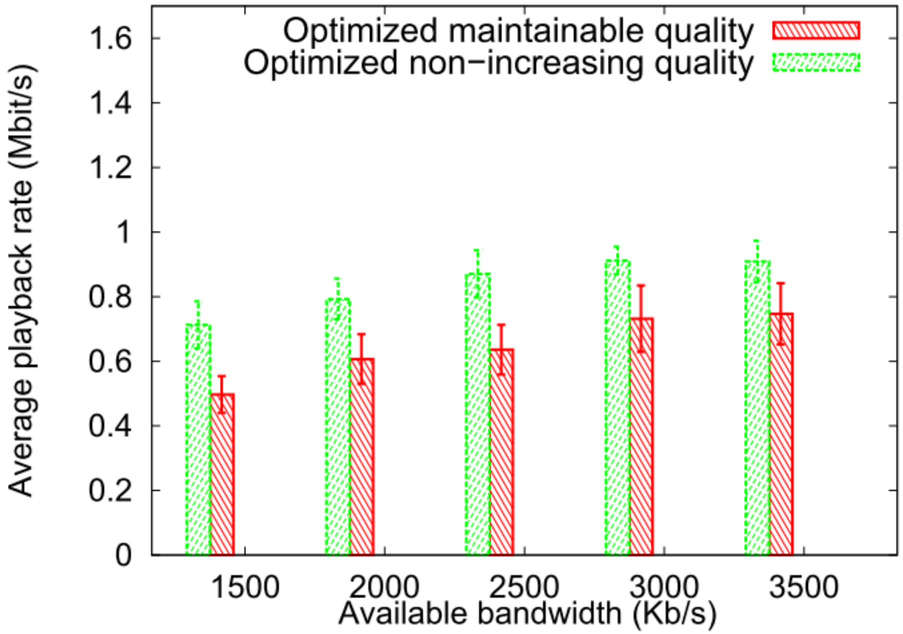

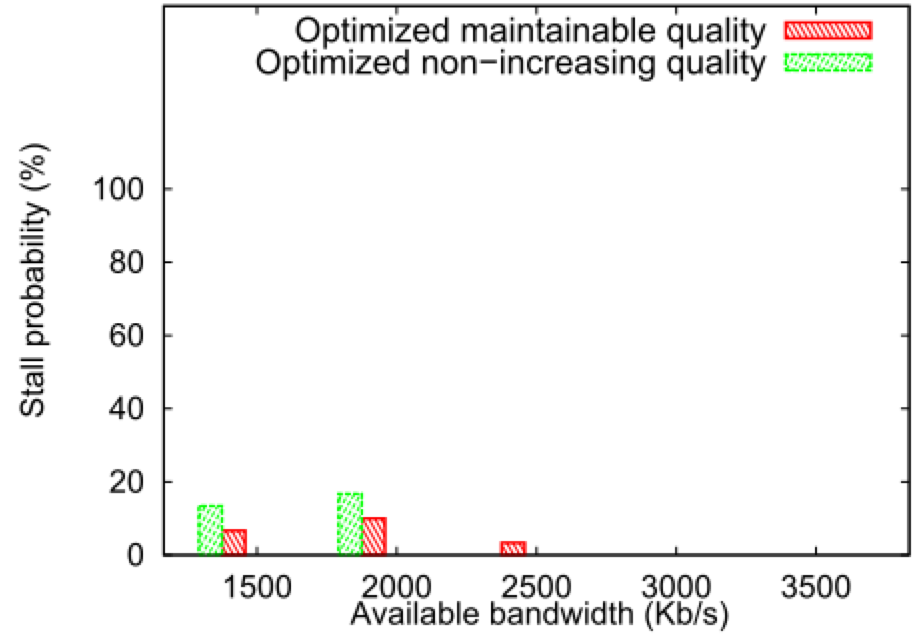

- *Optimized non-increasing quality* is more aggressive
  - Higher playback rate
  - More stalls

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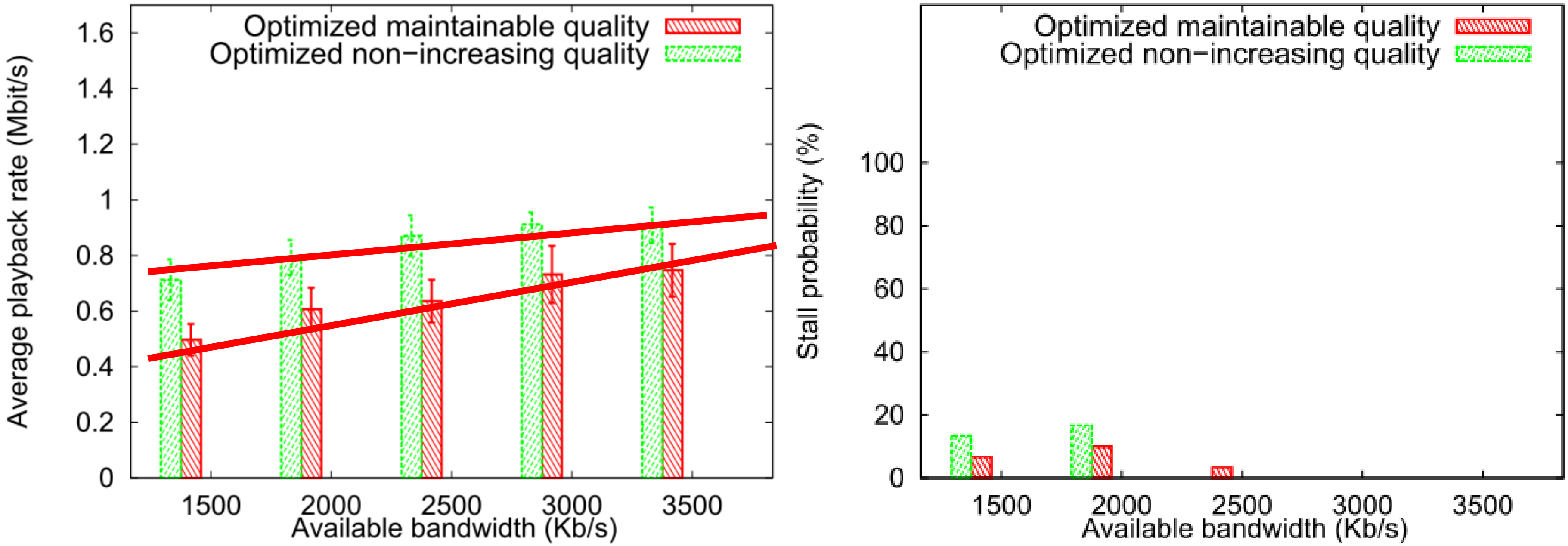

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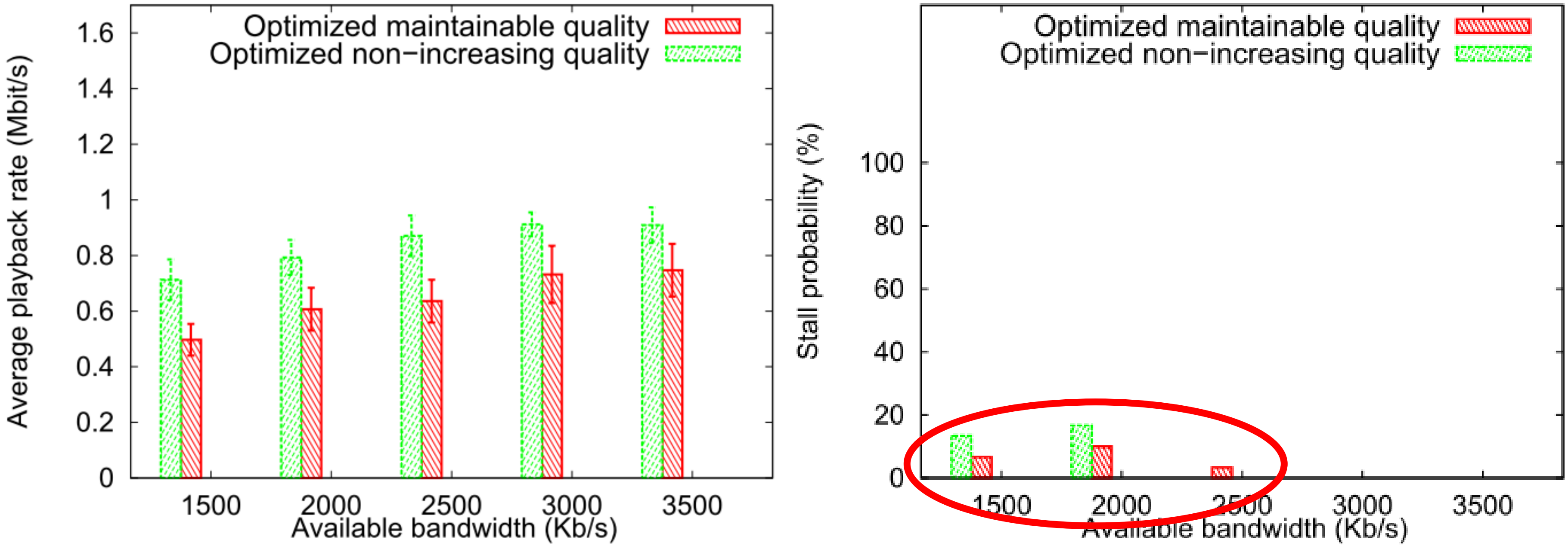

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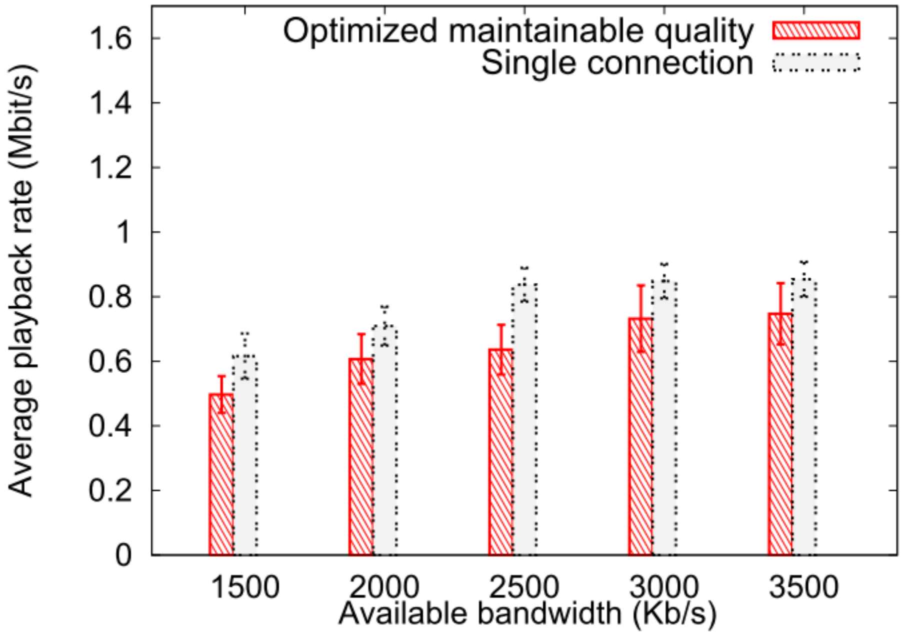
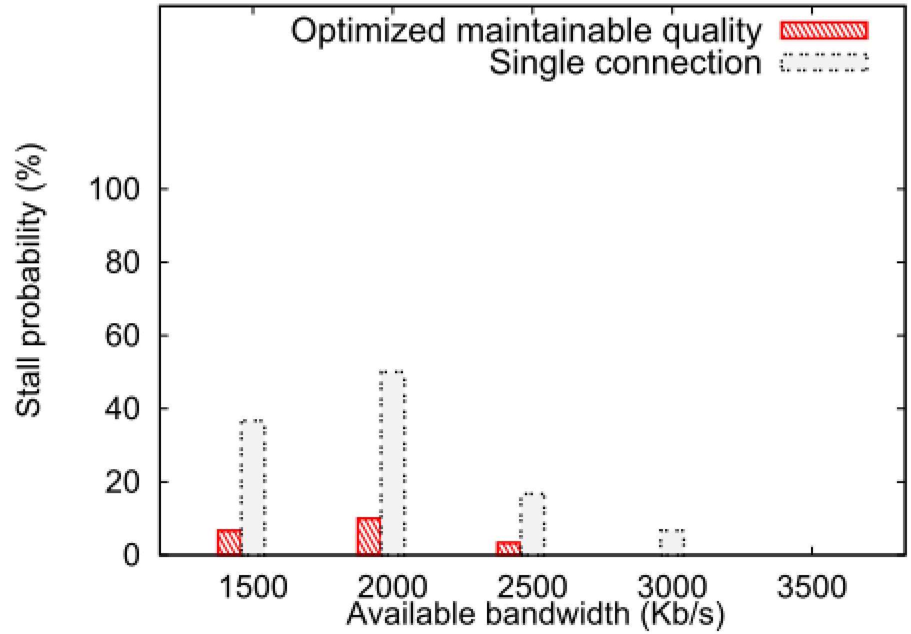
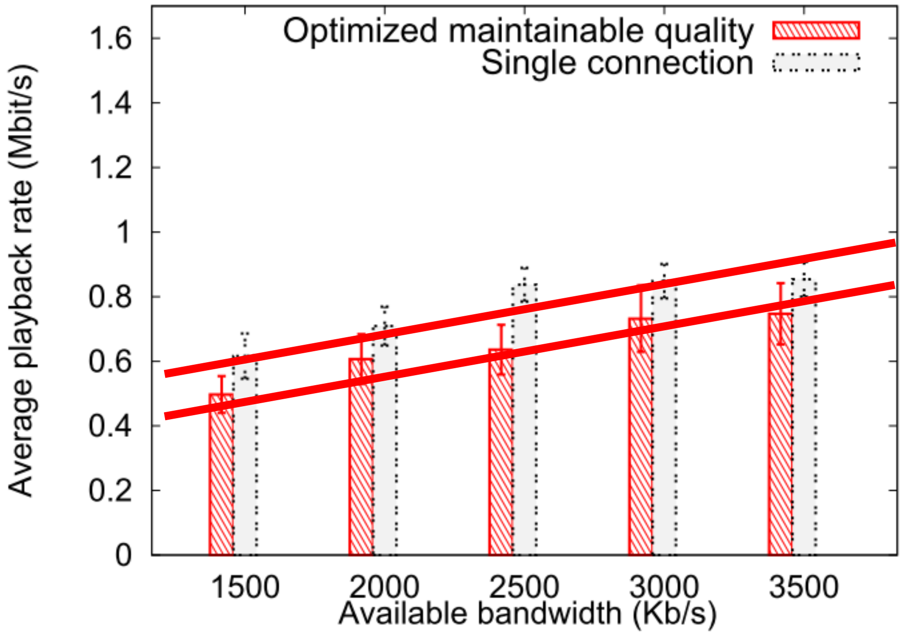
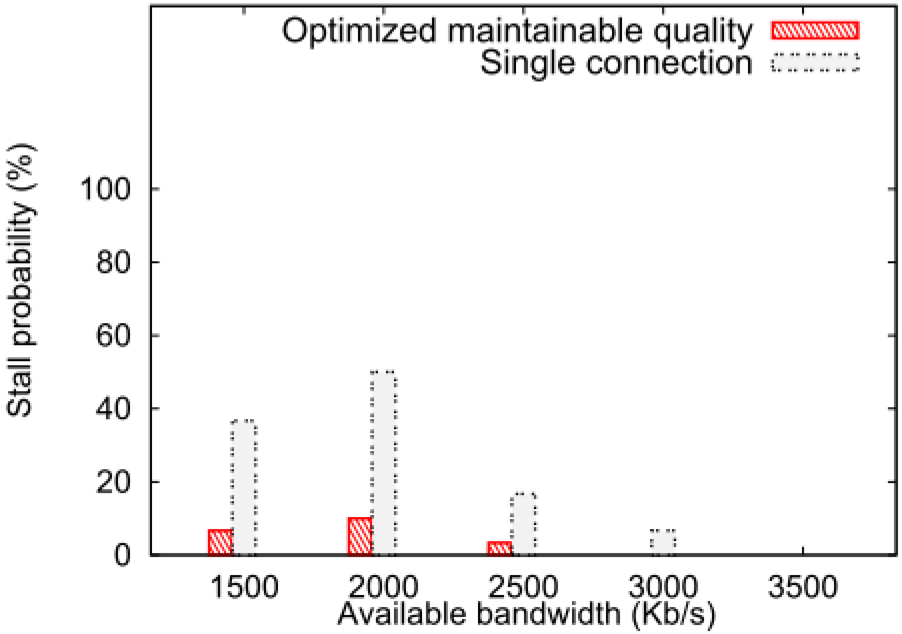




- *Single connection* does not use parallel connections
  - Good (slightly higher) playback rate
  - Much more stalls

Policy Comparison





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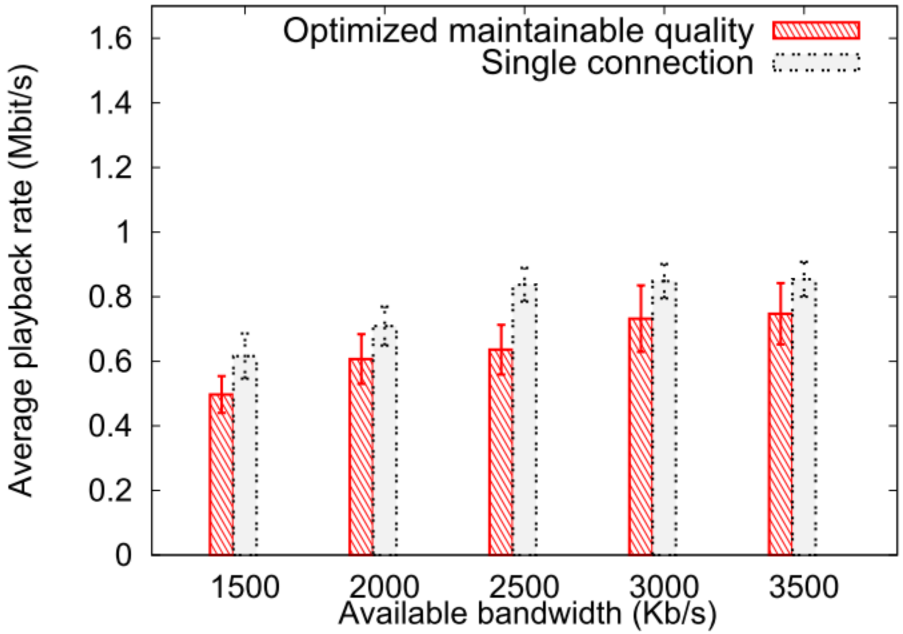

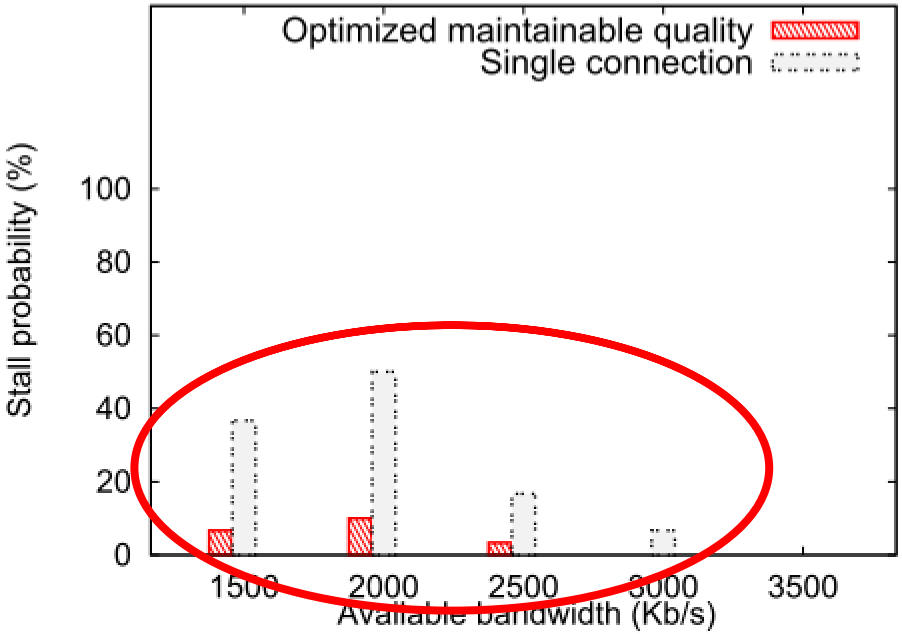

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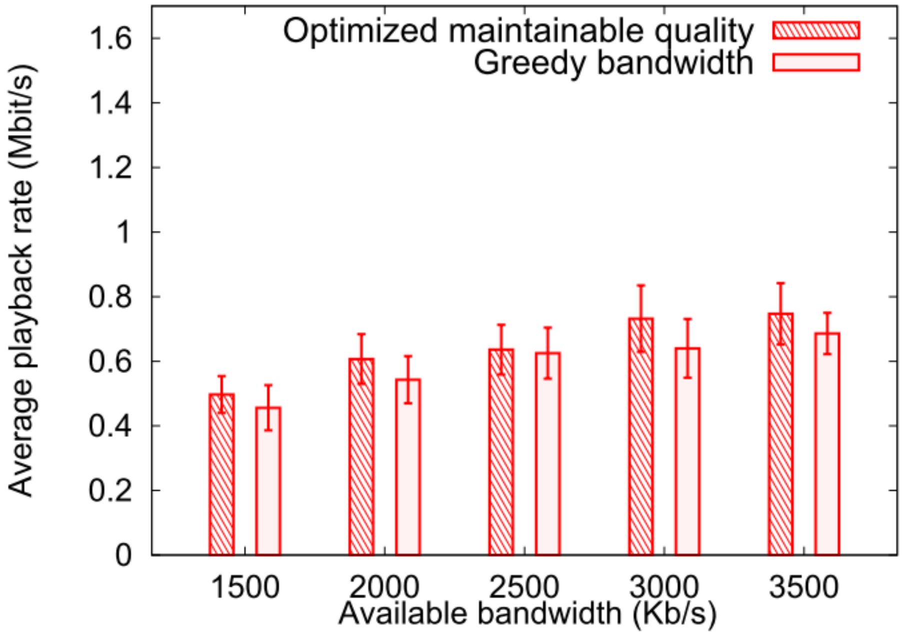
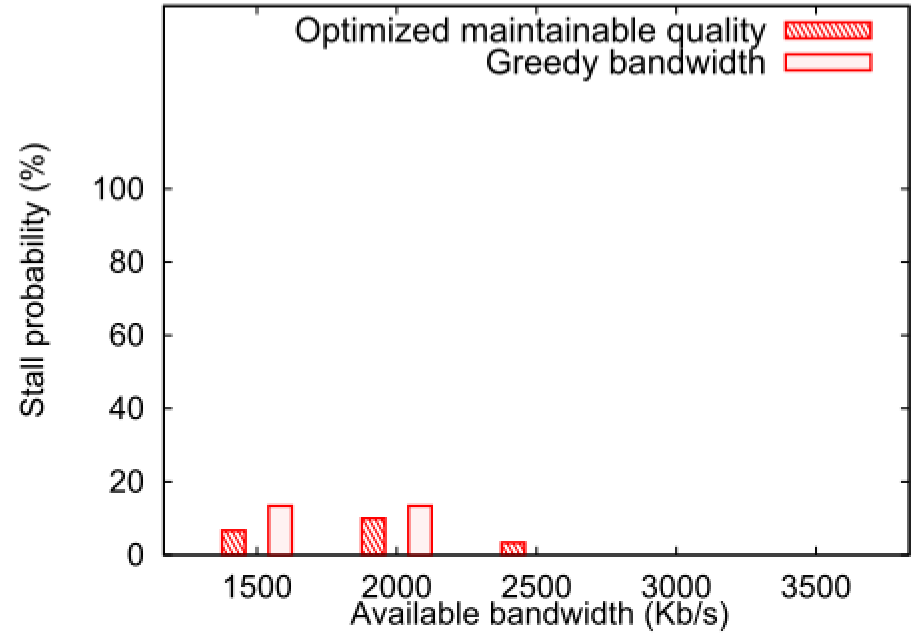
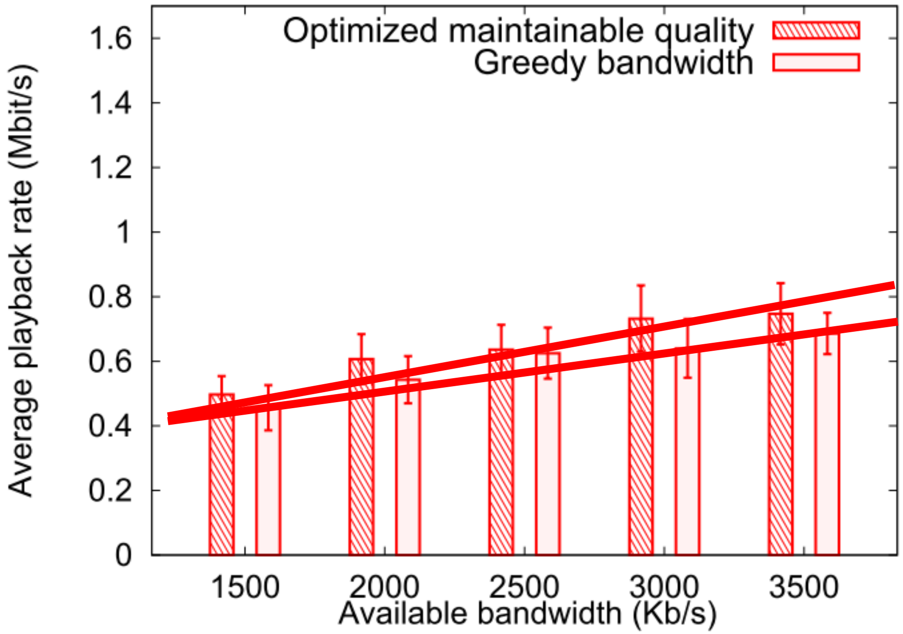
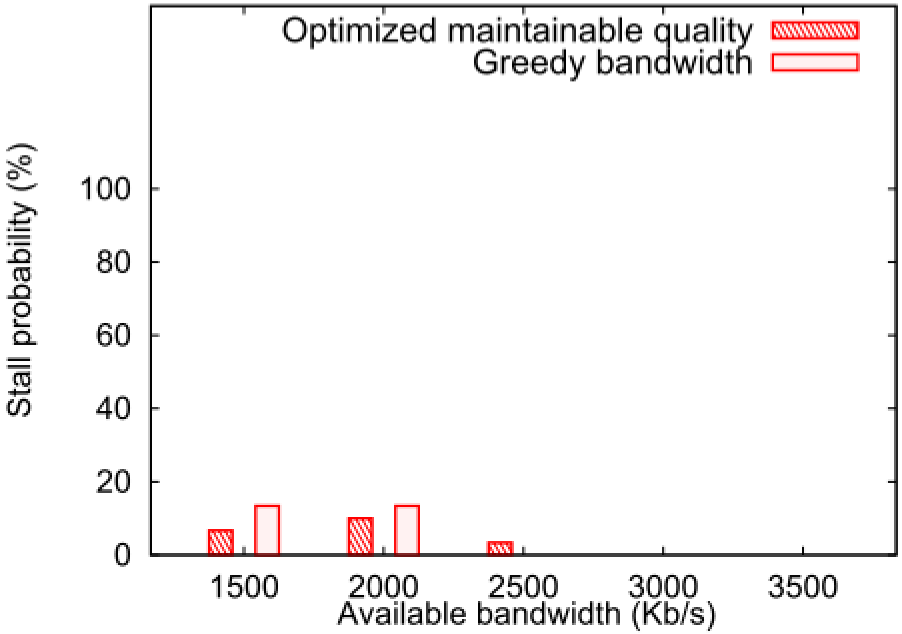




- *Greedy bandwidth* aggressively grabs bandwidth
  – Lower playback rate
  – More stalls

Policy Comparison





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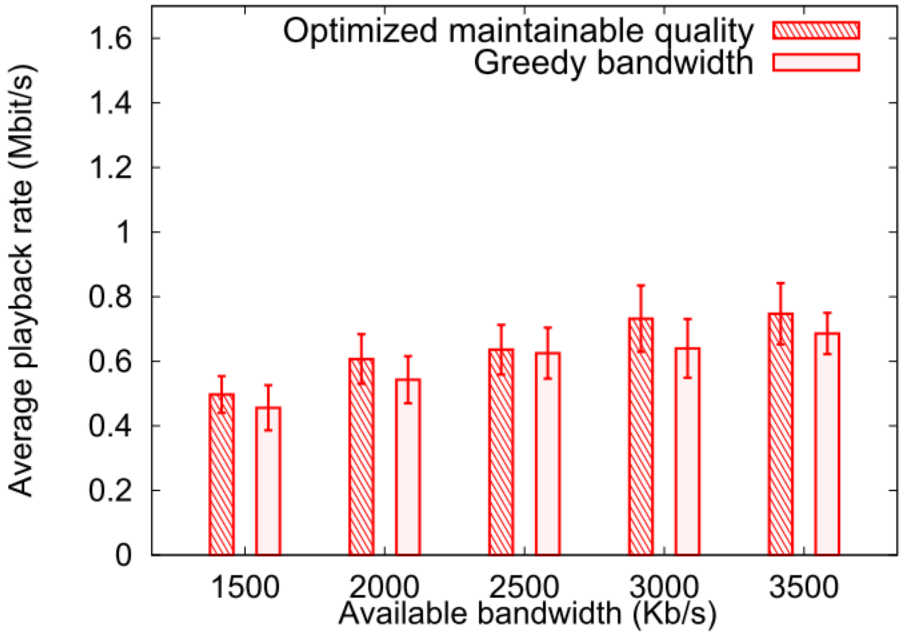
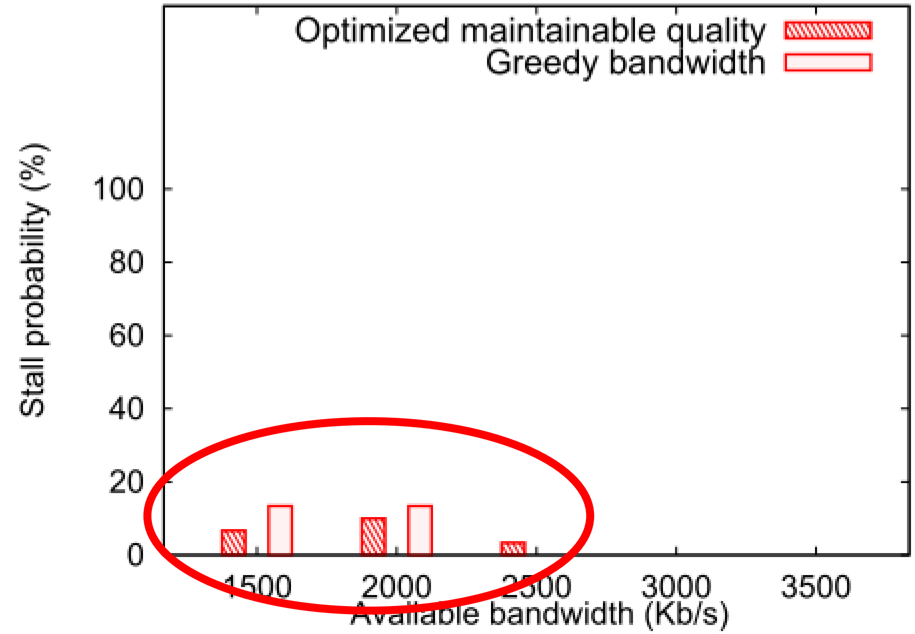
  - Lower playback rate
  - More stalls

Policy Comparison





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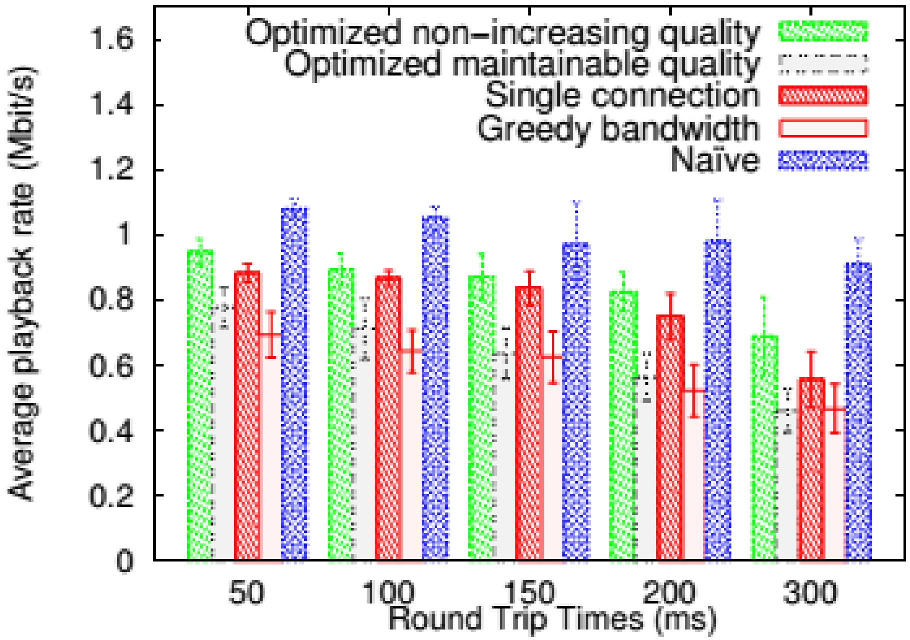
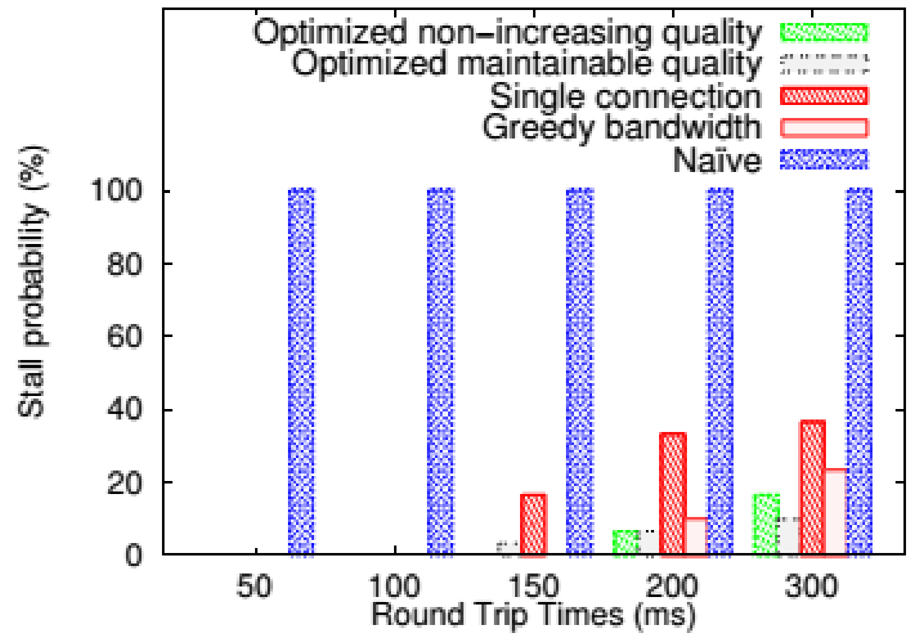
Impact of Round-trip Times (RTTs)





- Quality decreases with larger RTTs
  – Playback rate decrease with RTT
  – Stall probability increase with RTT

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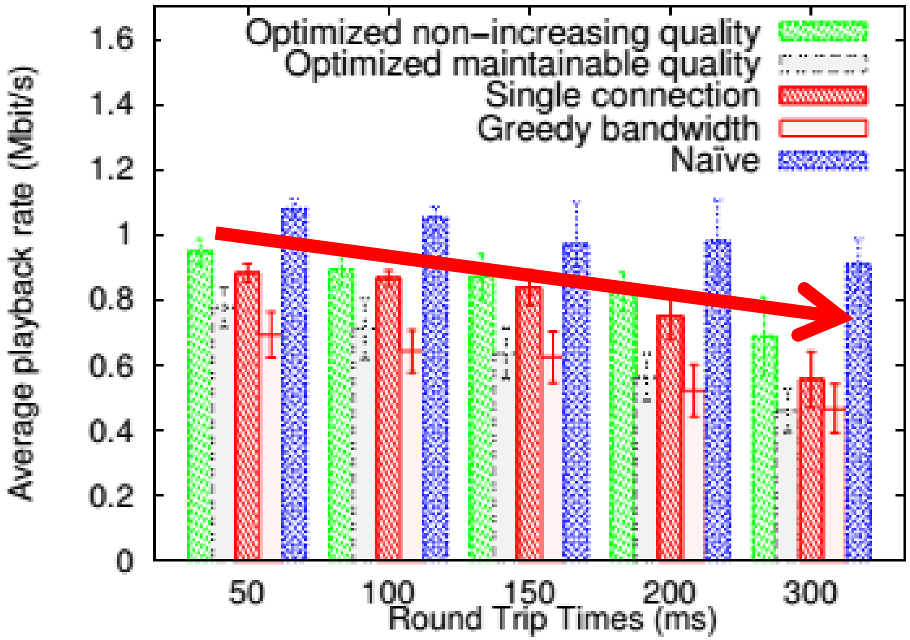

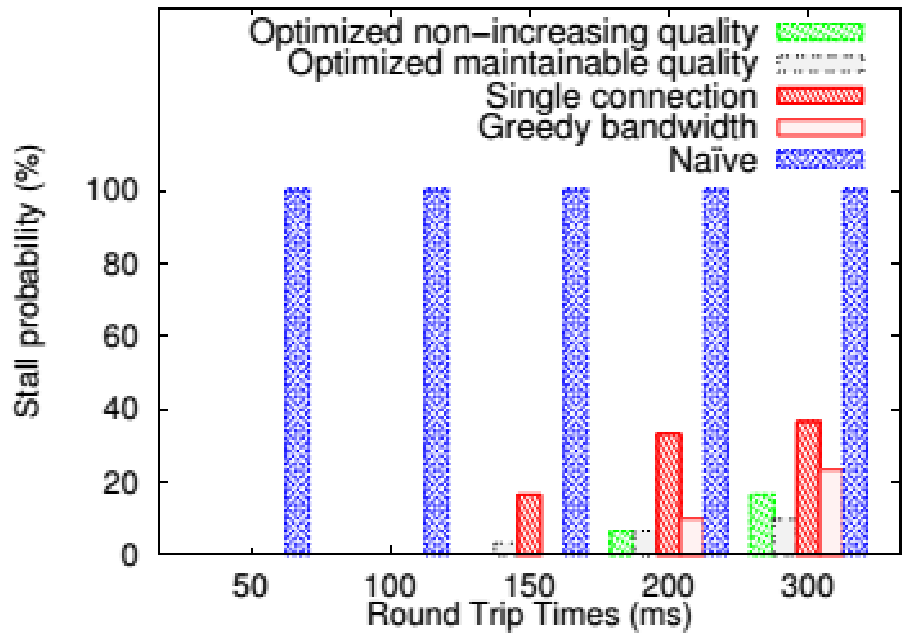

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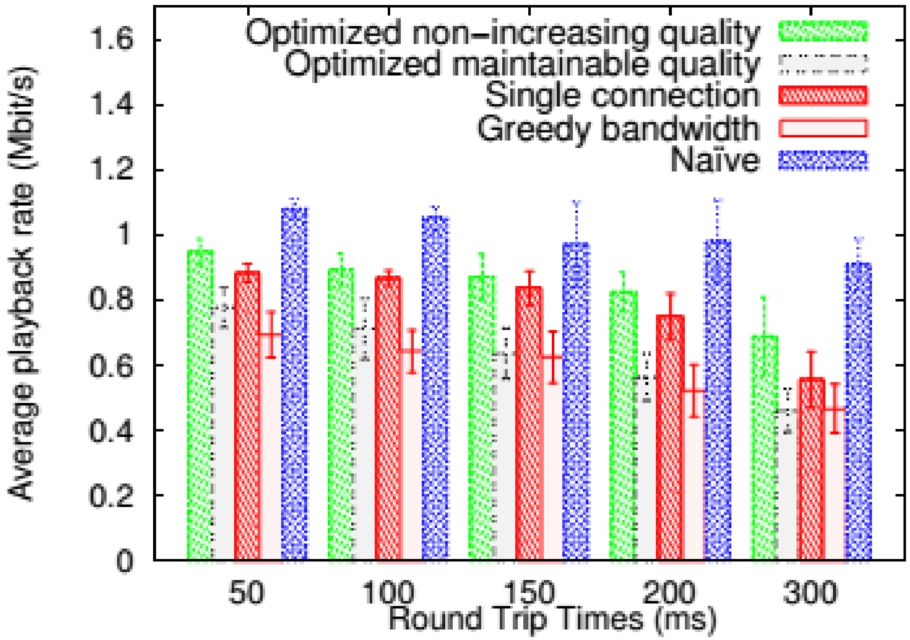

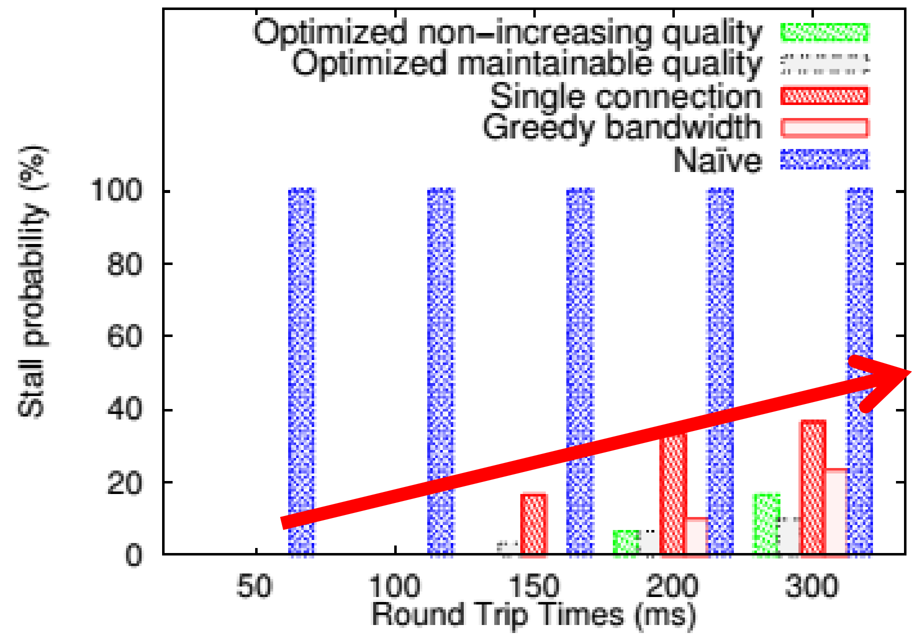

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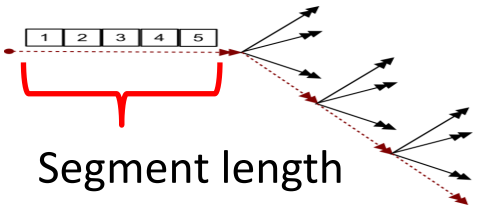
Impact of Segment Lengths



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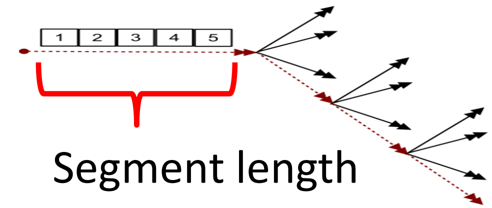
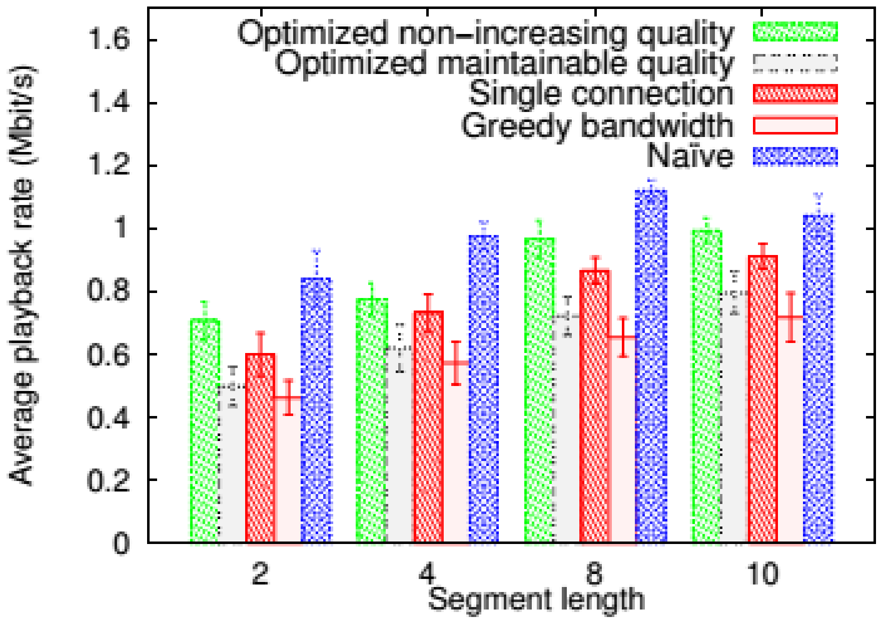
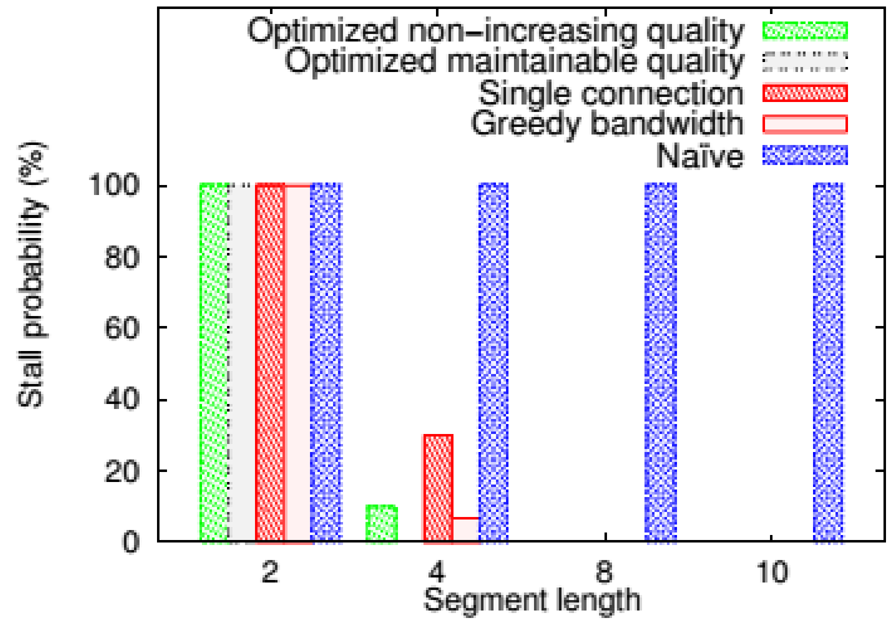
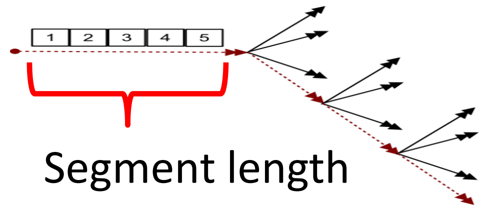


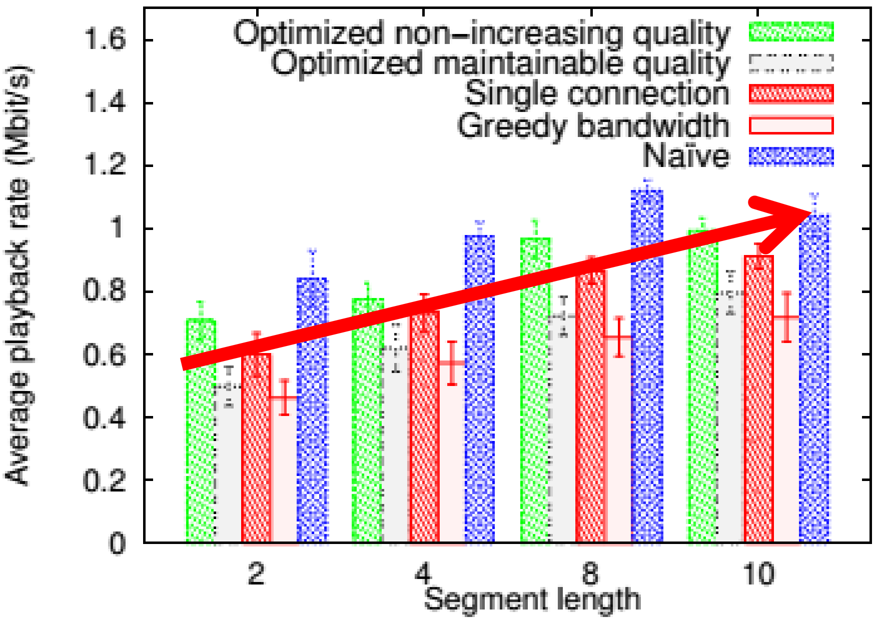


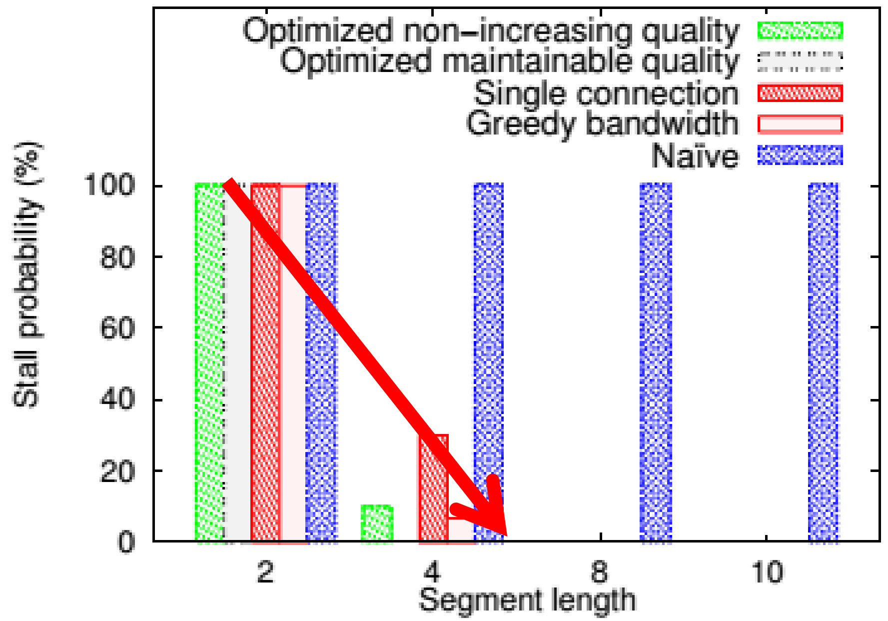


- Quality increases with more chunks per segment
- Very many stalls if segments are too short

Impact of Segment Lengths







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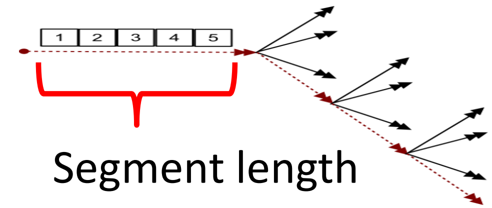

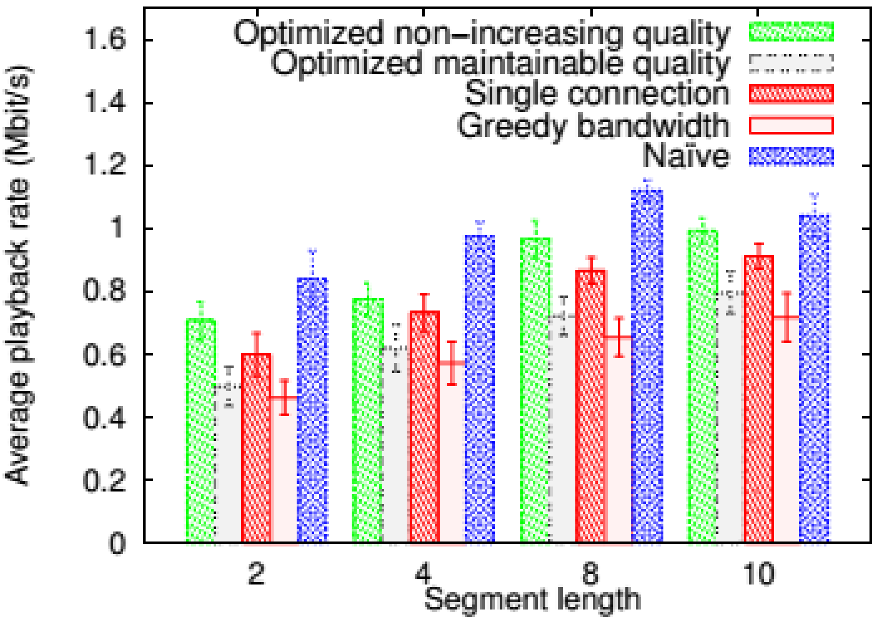

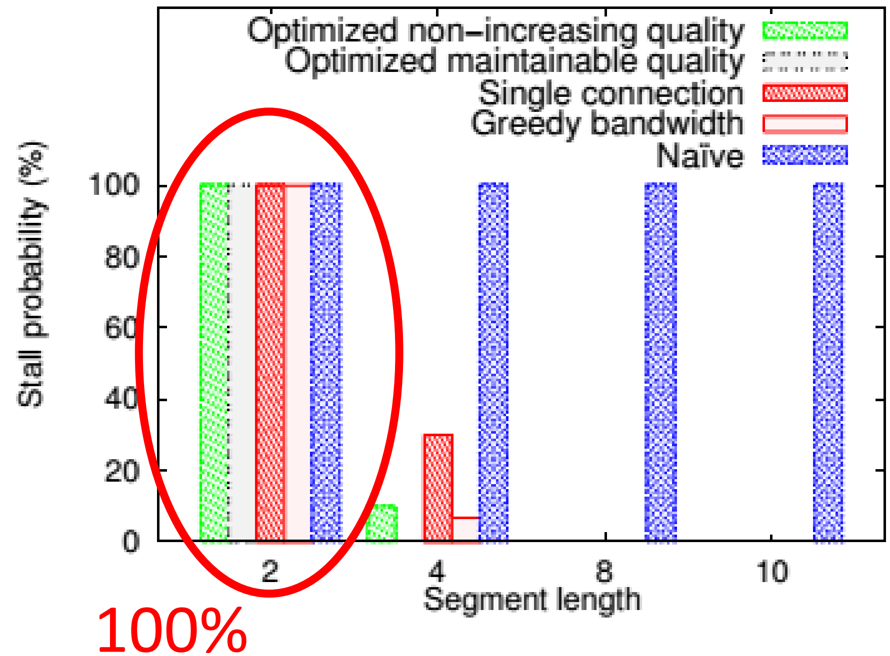

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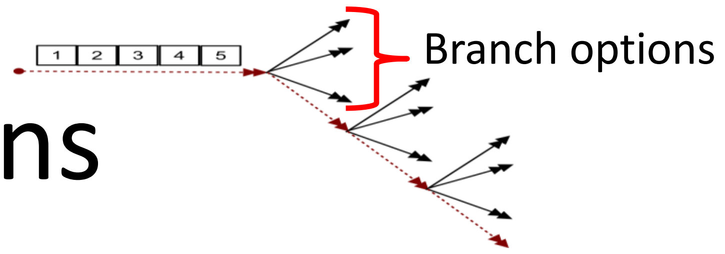
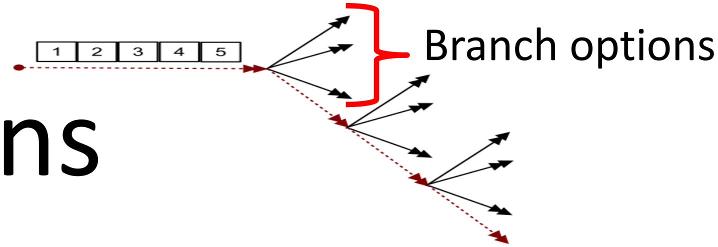
Impact of Branch Options





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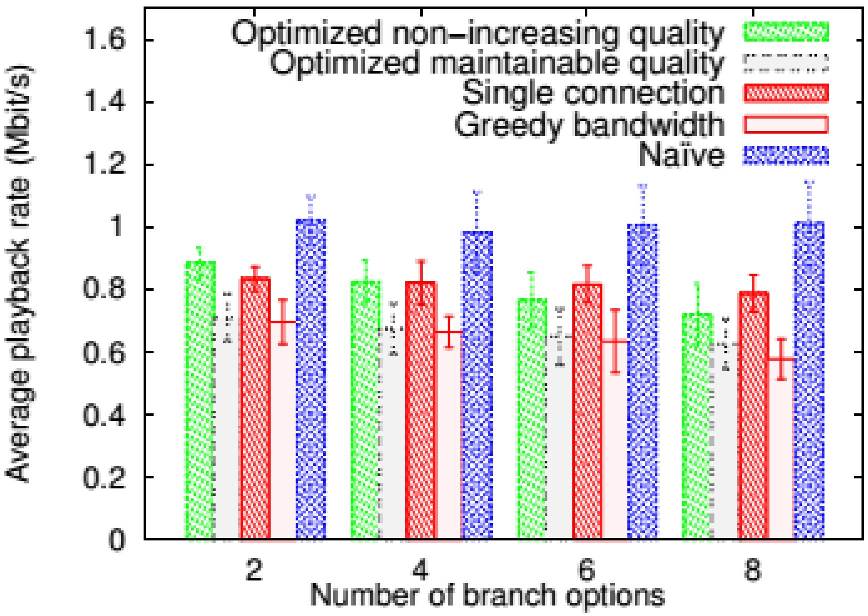
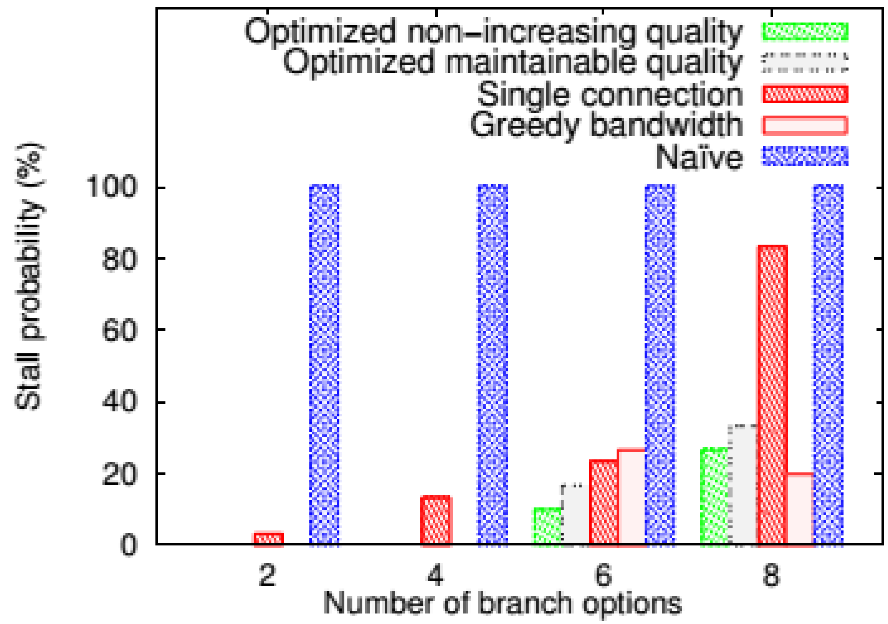
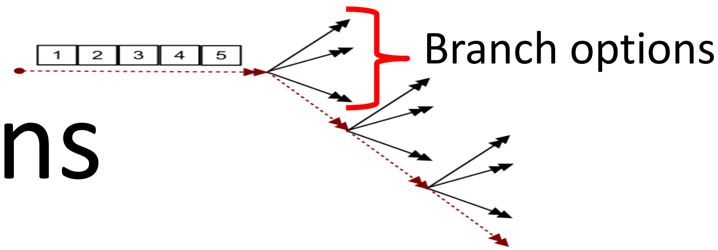
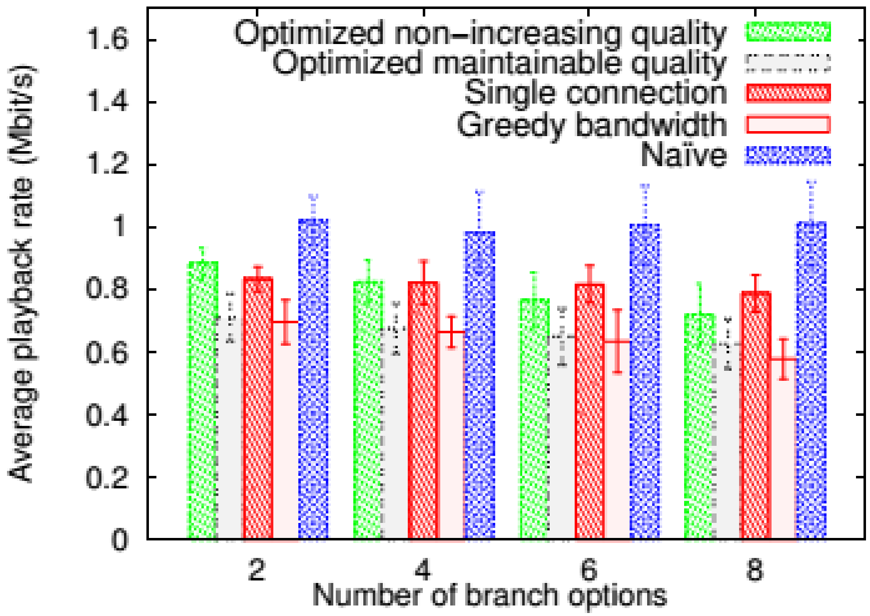


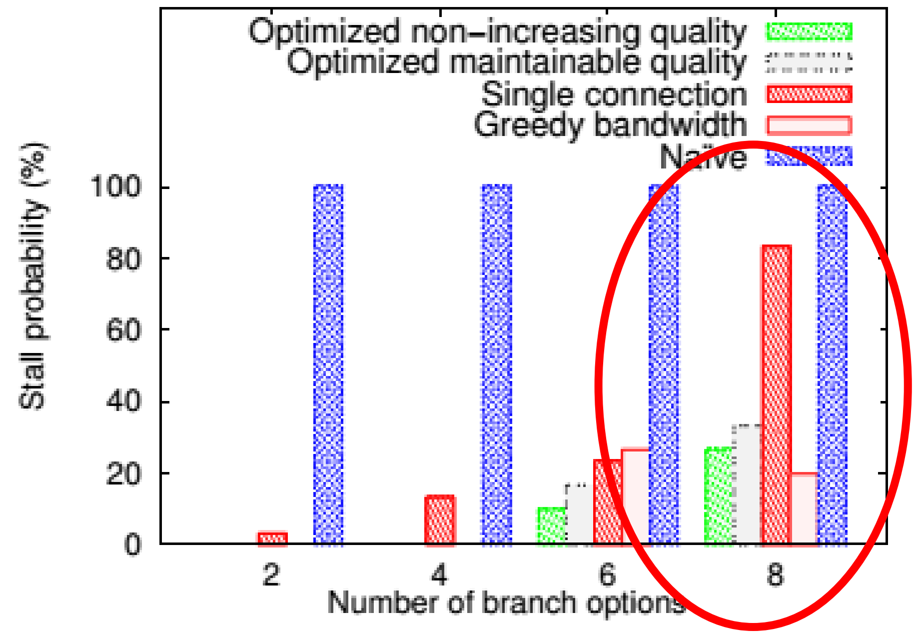


- Stalls frequent when too many branch options
  - Single connection struggles the most

Impact of Branch Options







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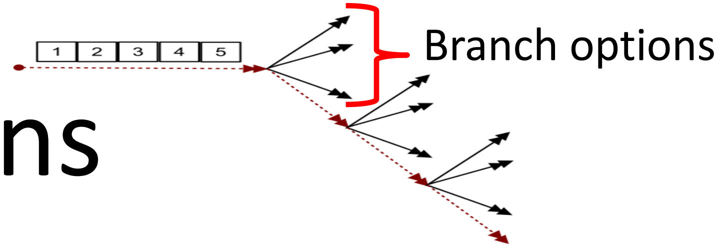

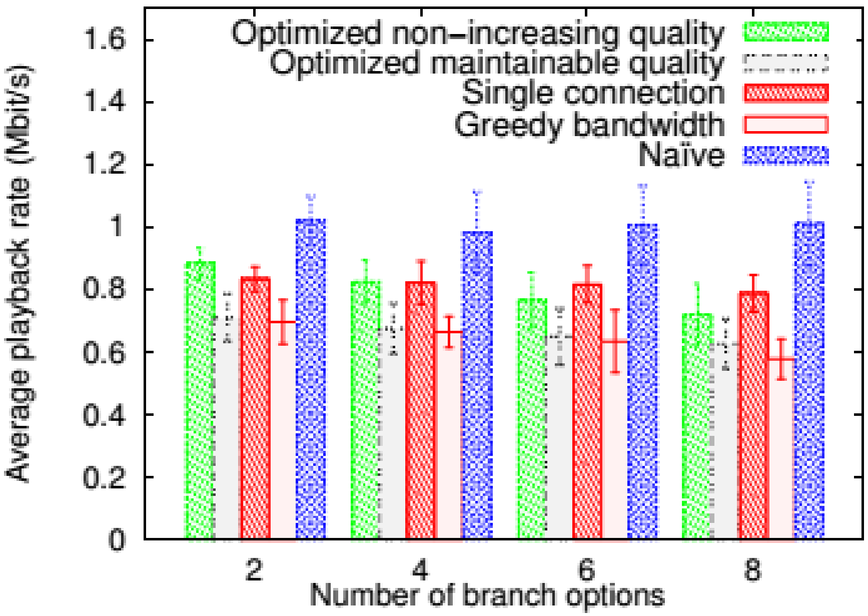

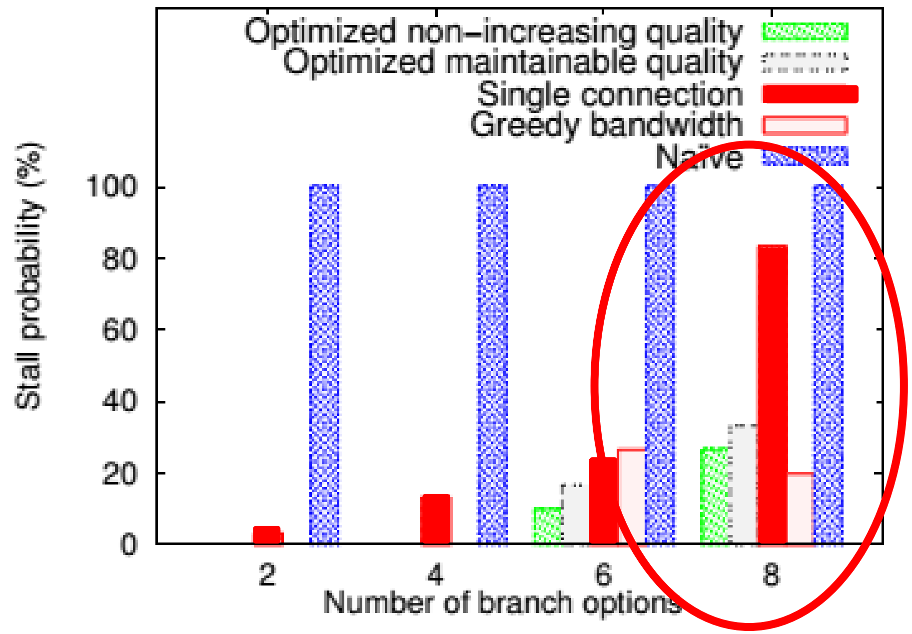

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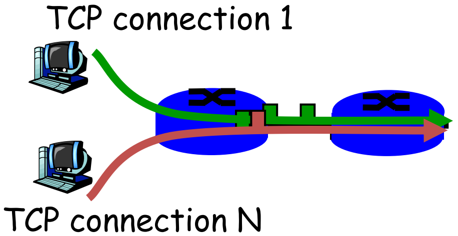
Impact of Competing Flows



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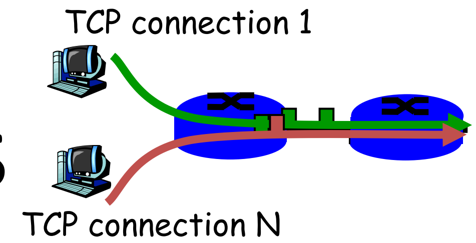

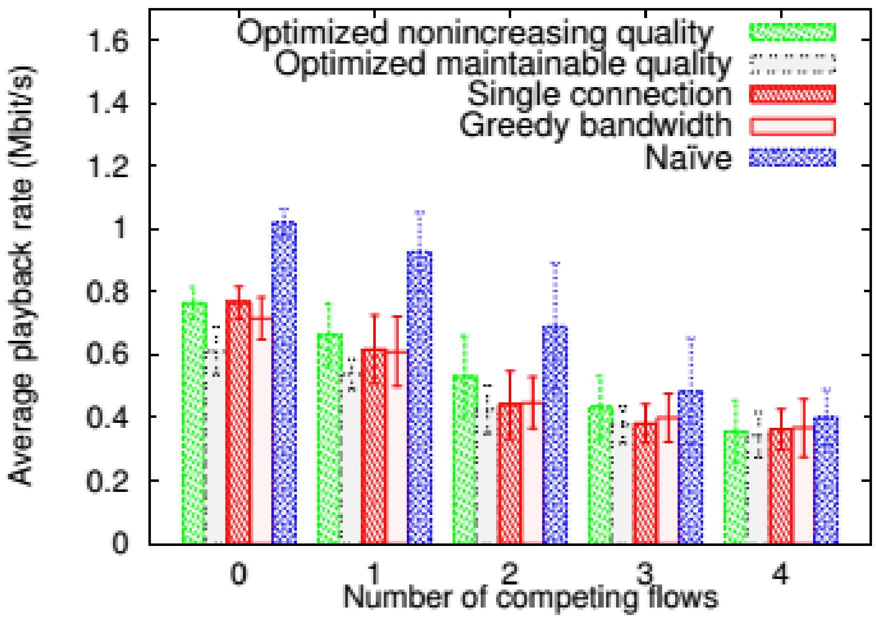

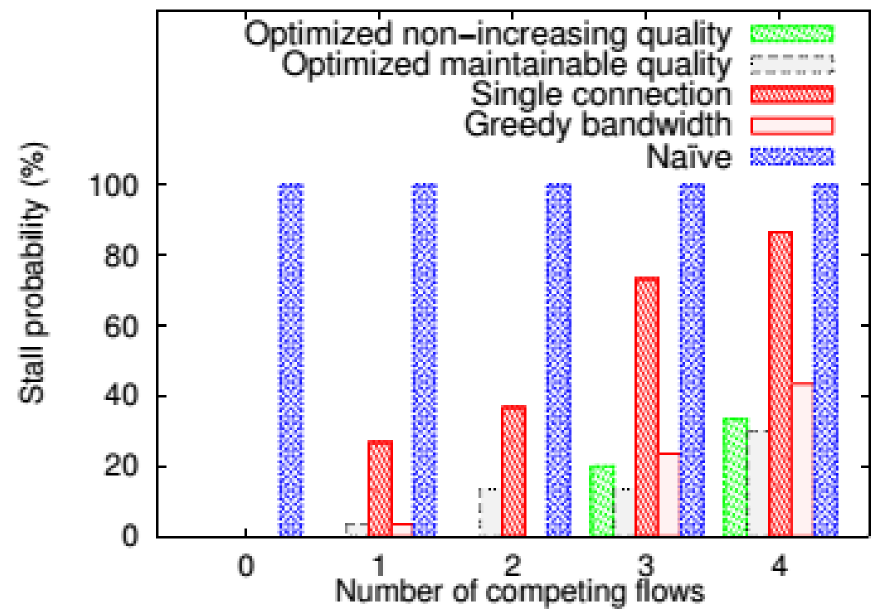

- Player adapts playback rate based on competing traffic
- Parallel connection polices see increased benefits when competing traffic
  - E.g., Single connection policy has much more stalls when competing flows

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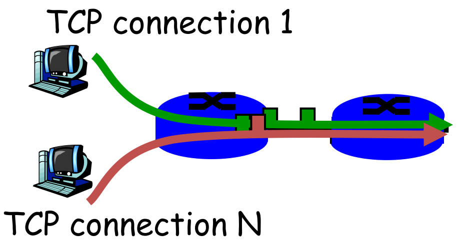

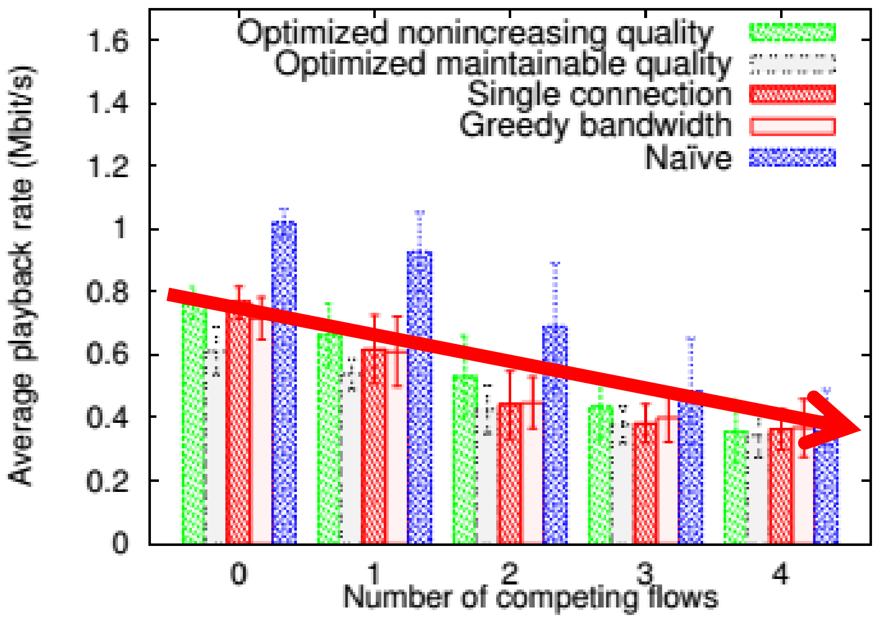

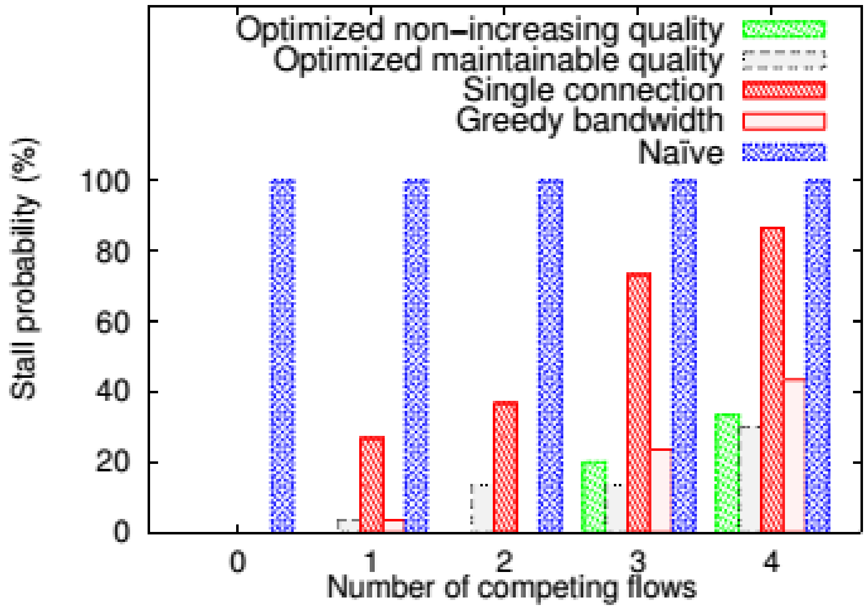

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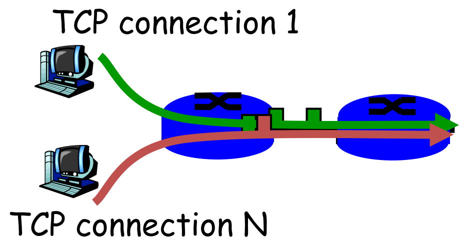

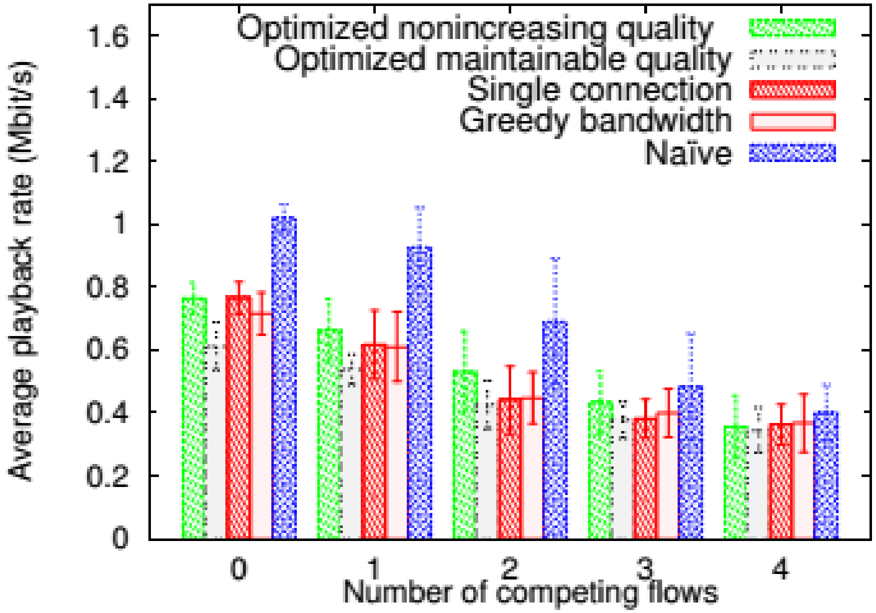

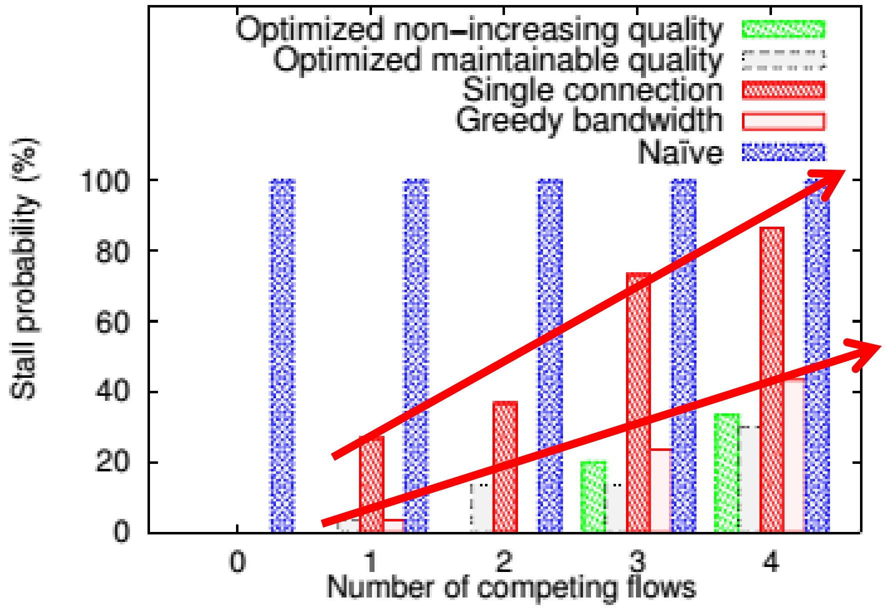

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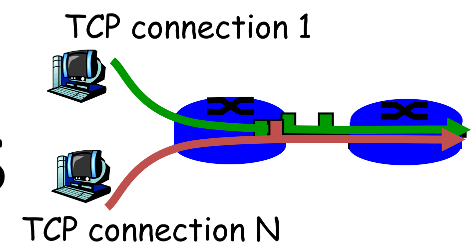

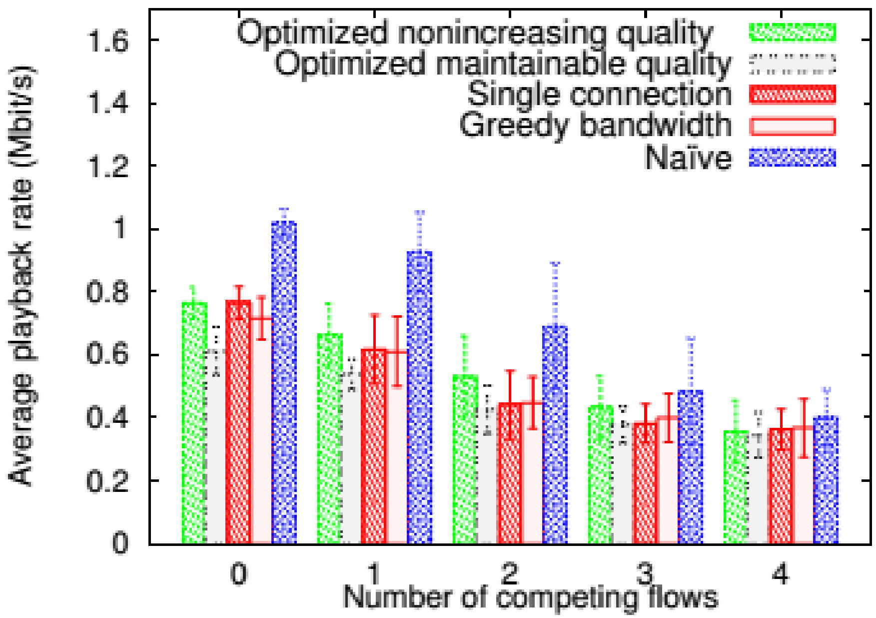

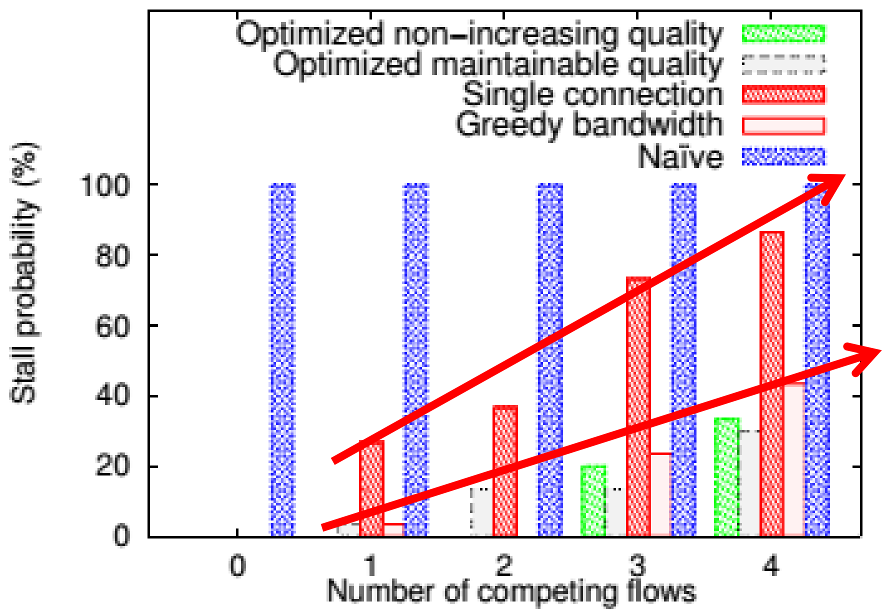

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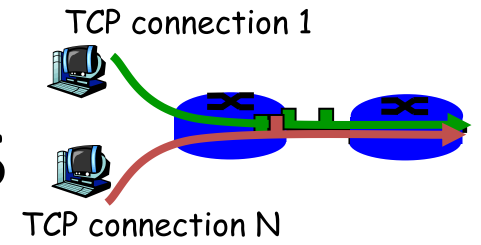

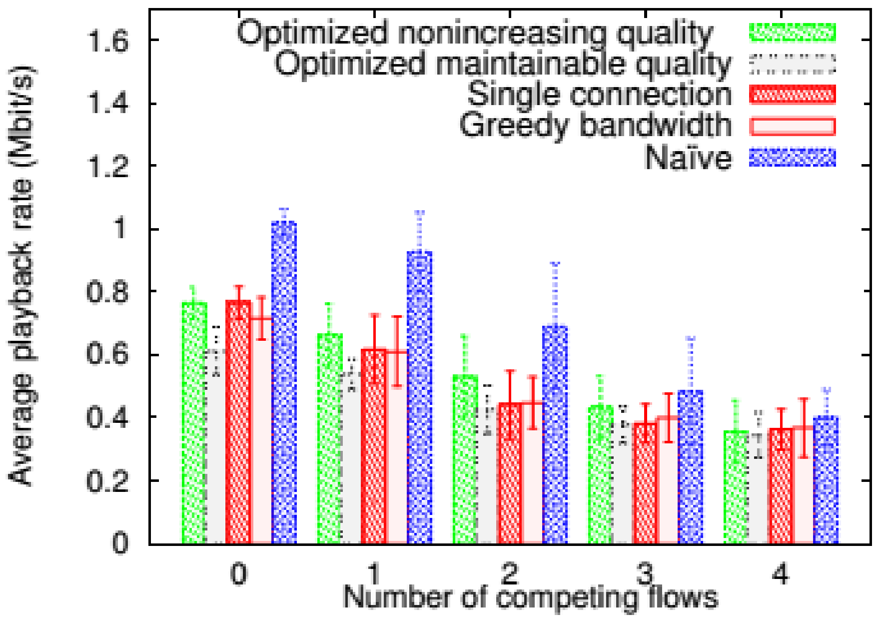

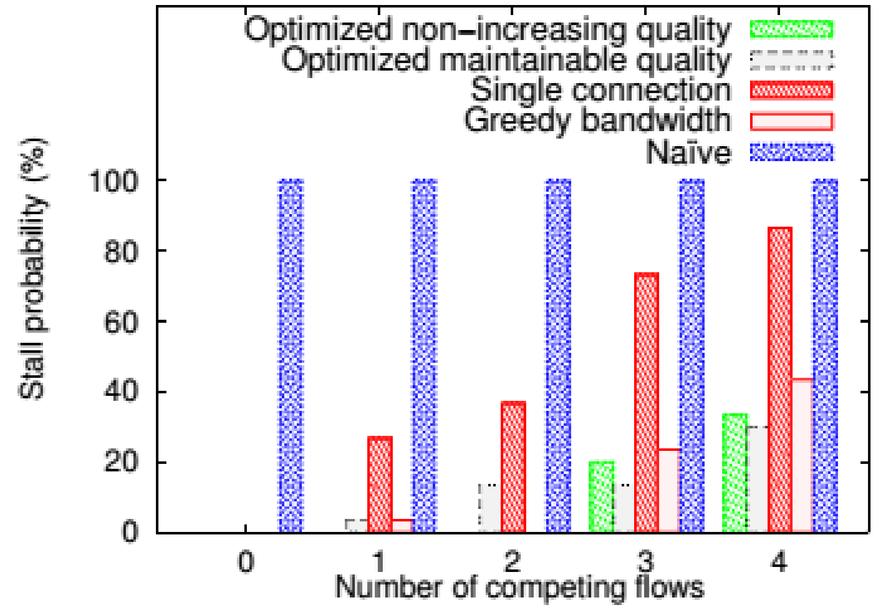

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Capped Workahead

- Most HAS players perform ON-OFF switching based on two buffer thresholds: T_{min} and T_{max}
- If buffer > T_{min}
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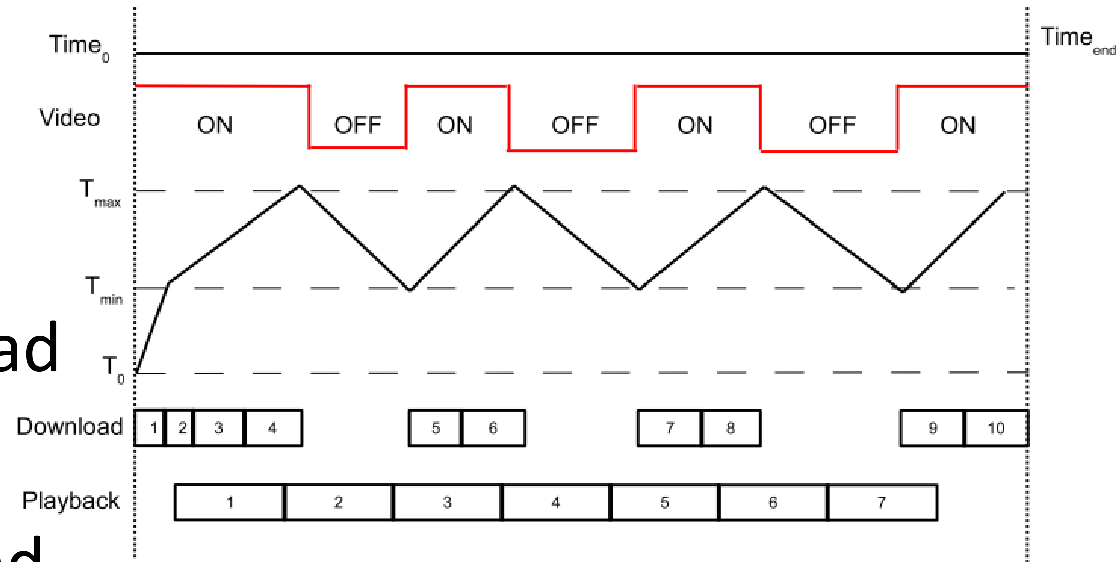

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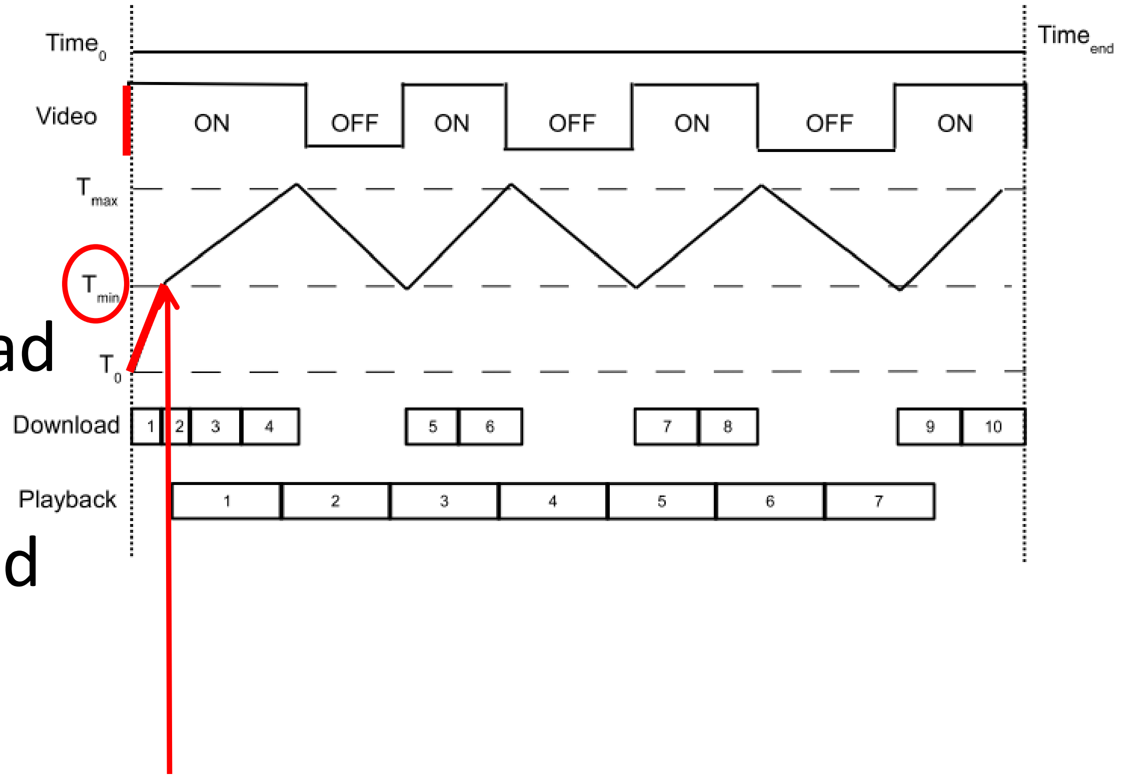

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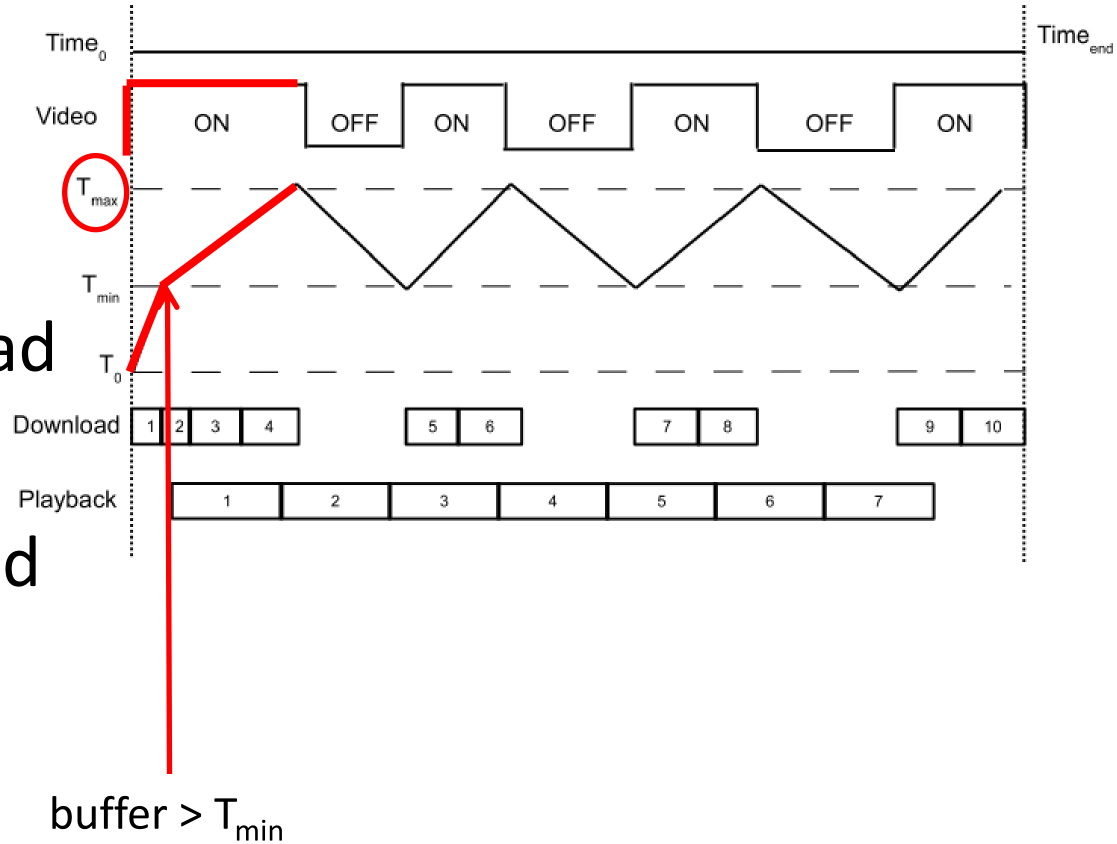

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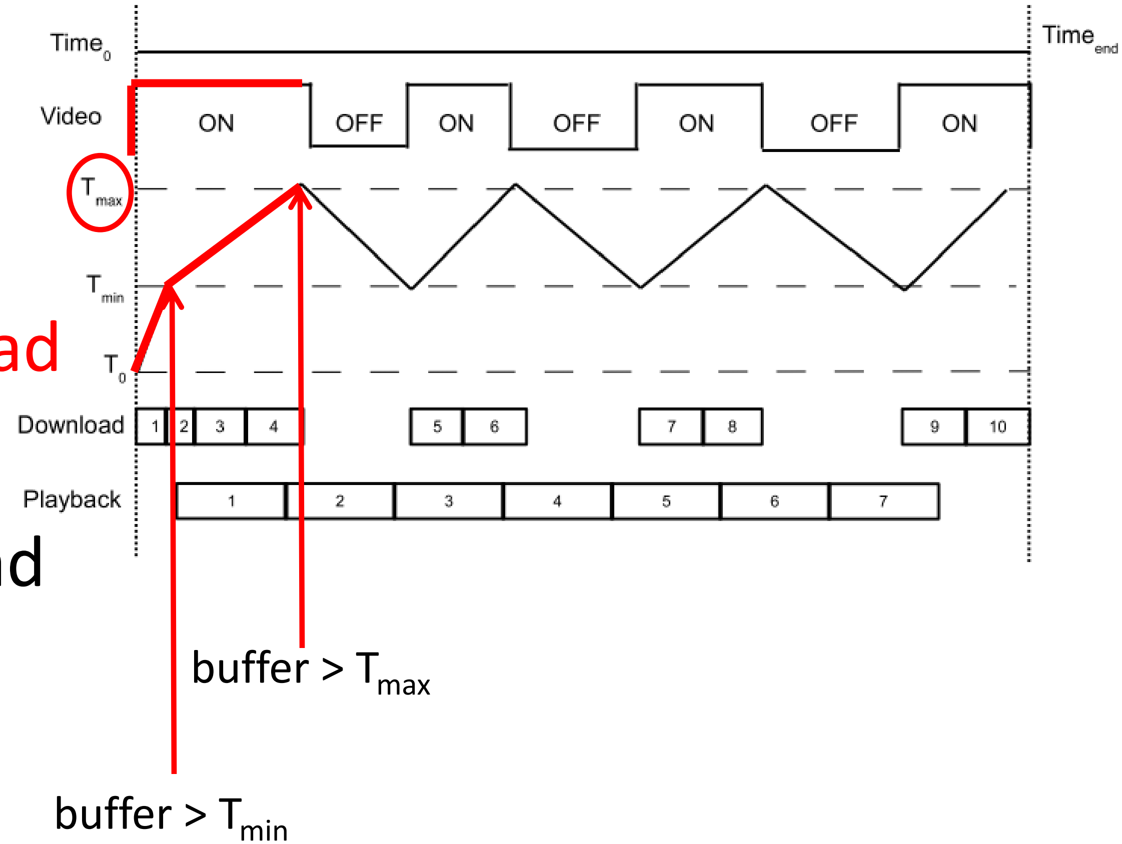

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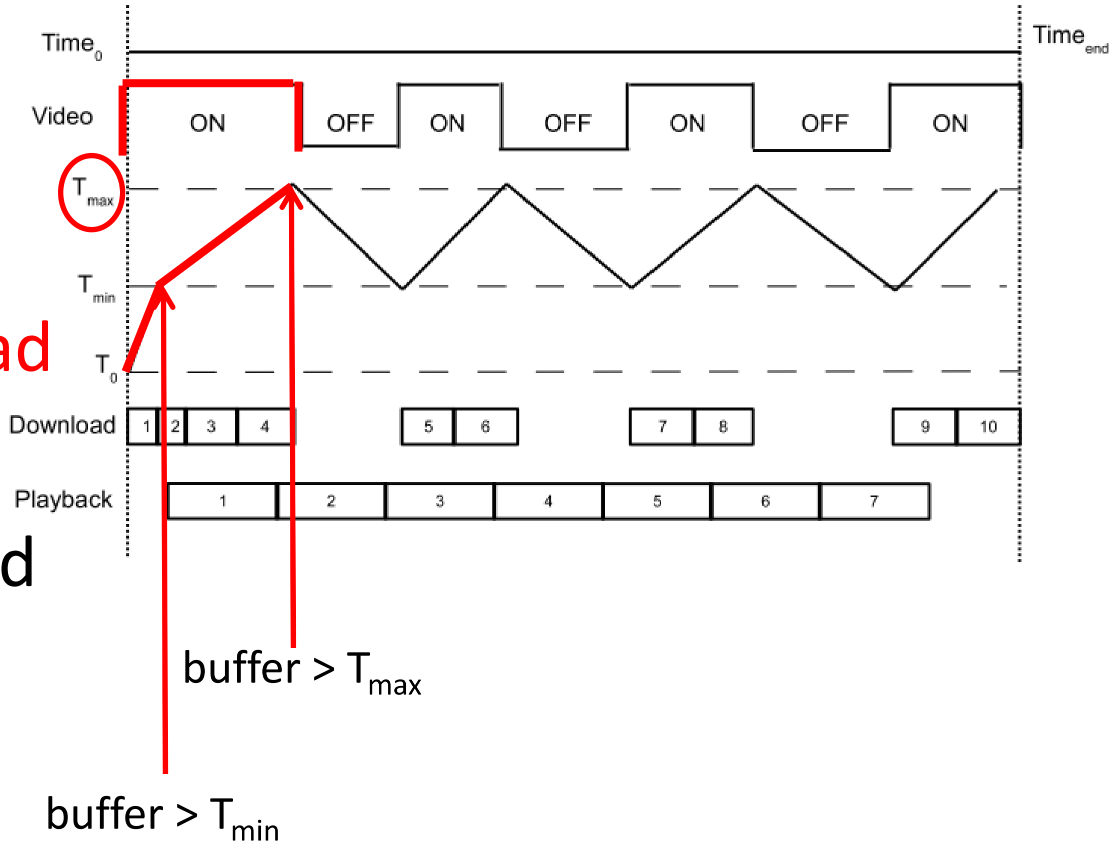

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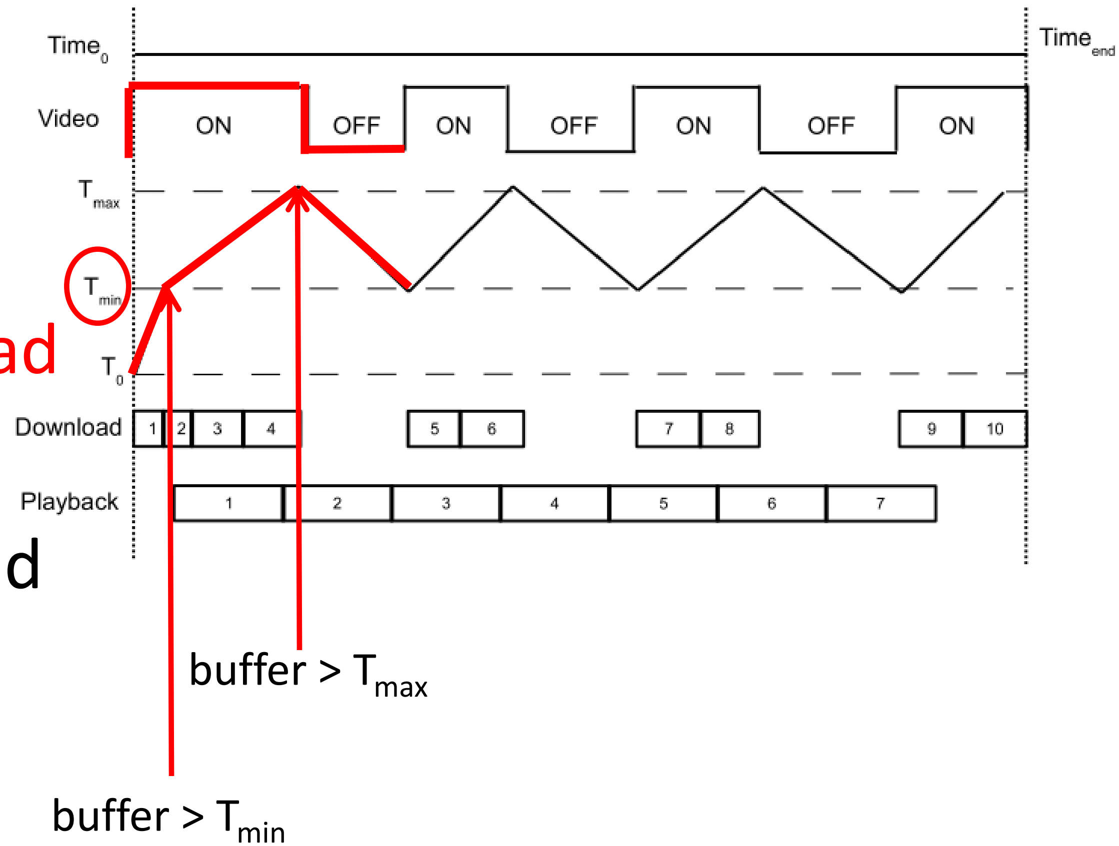

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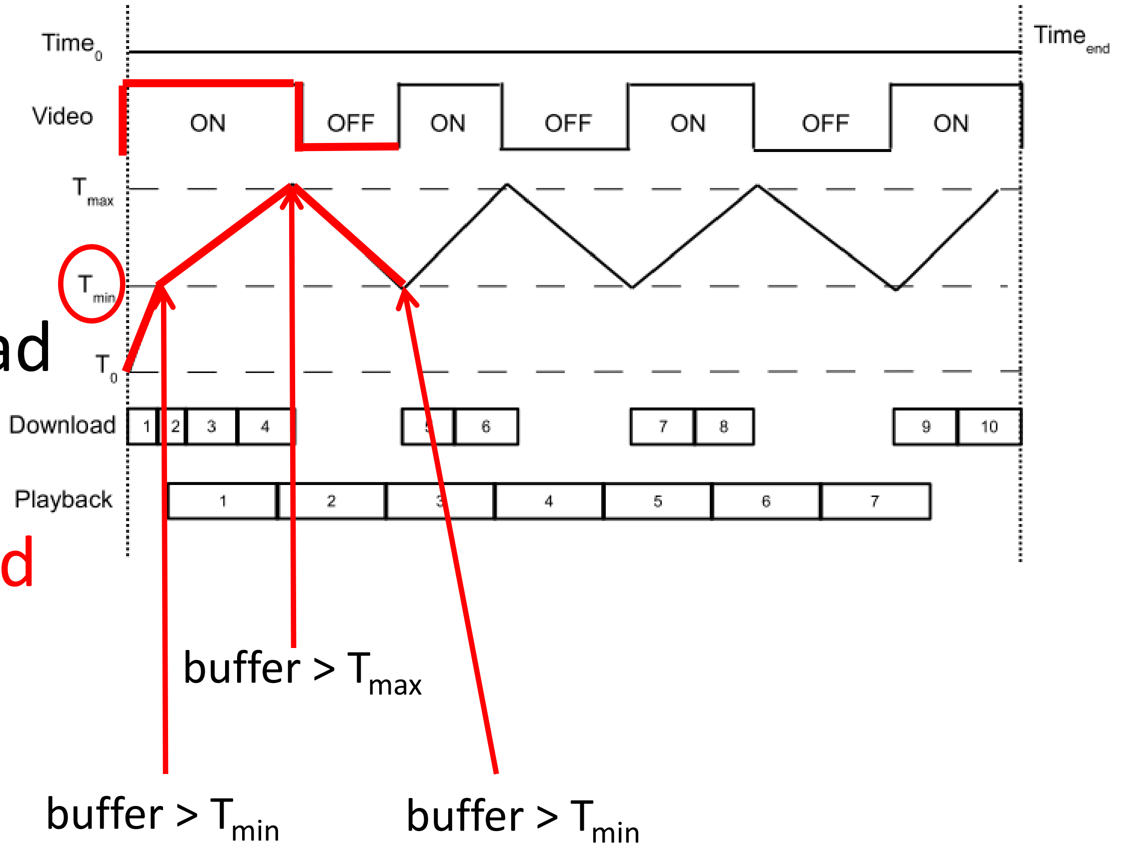

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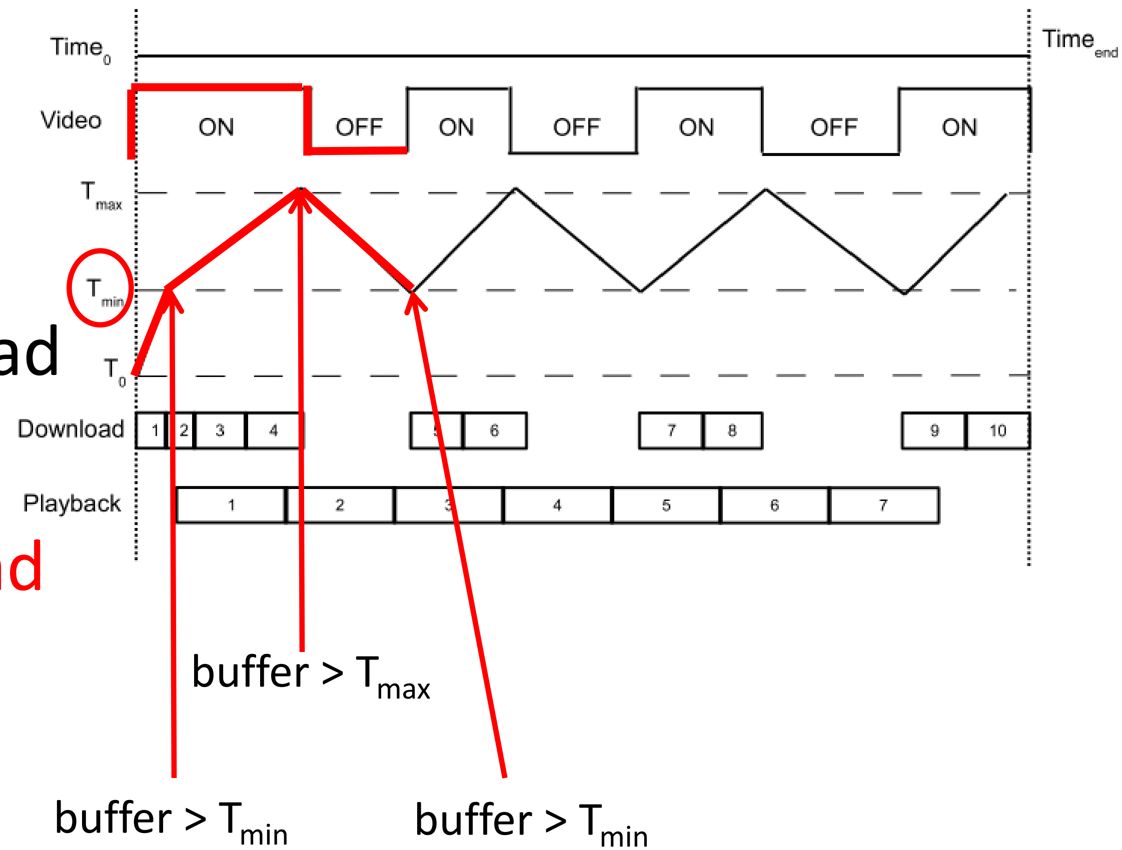

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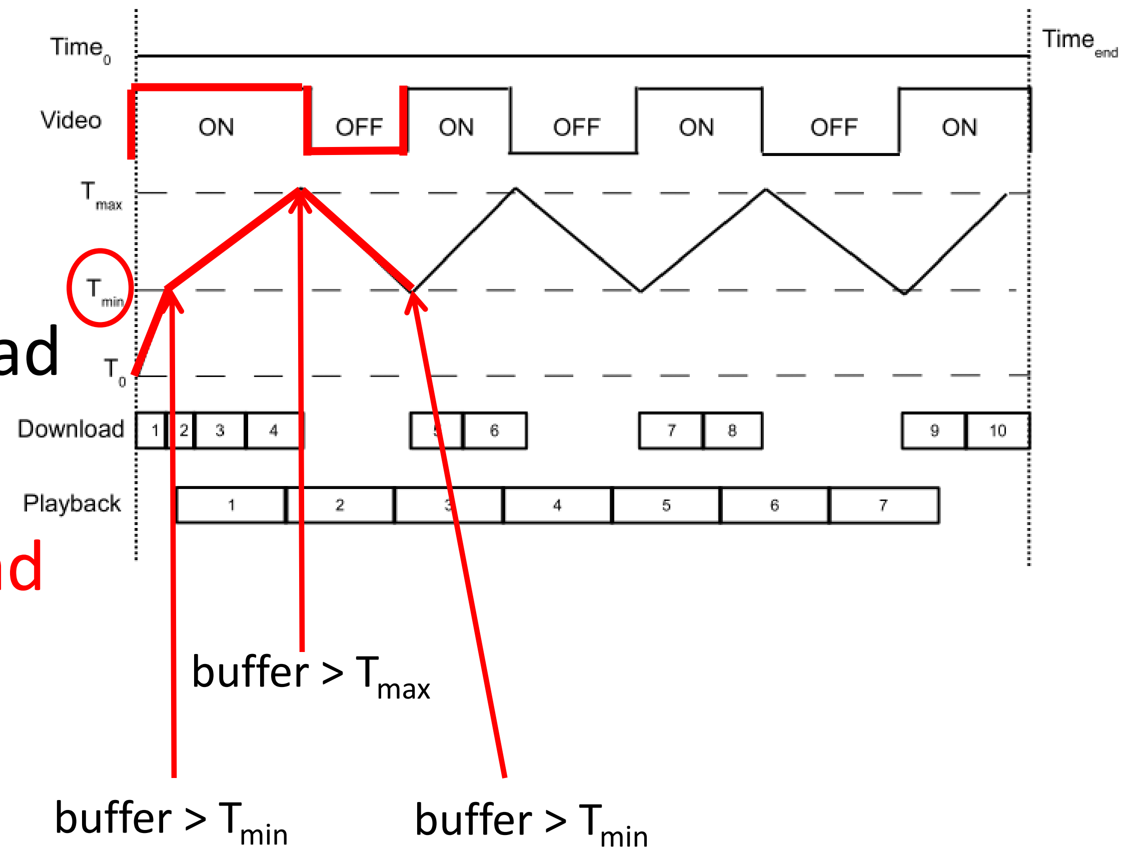

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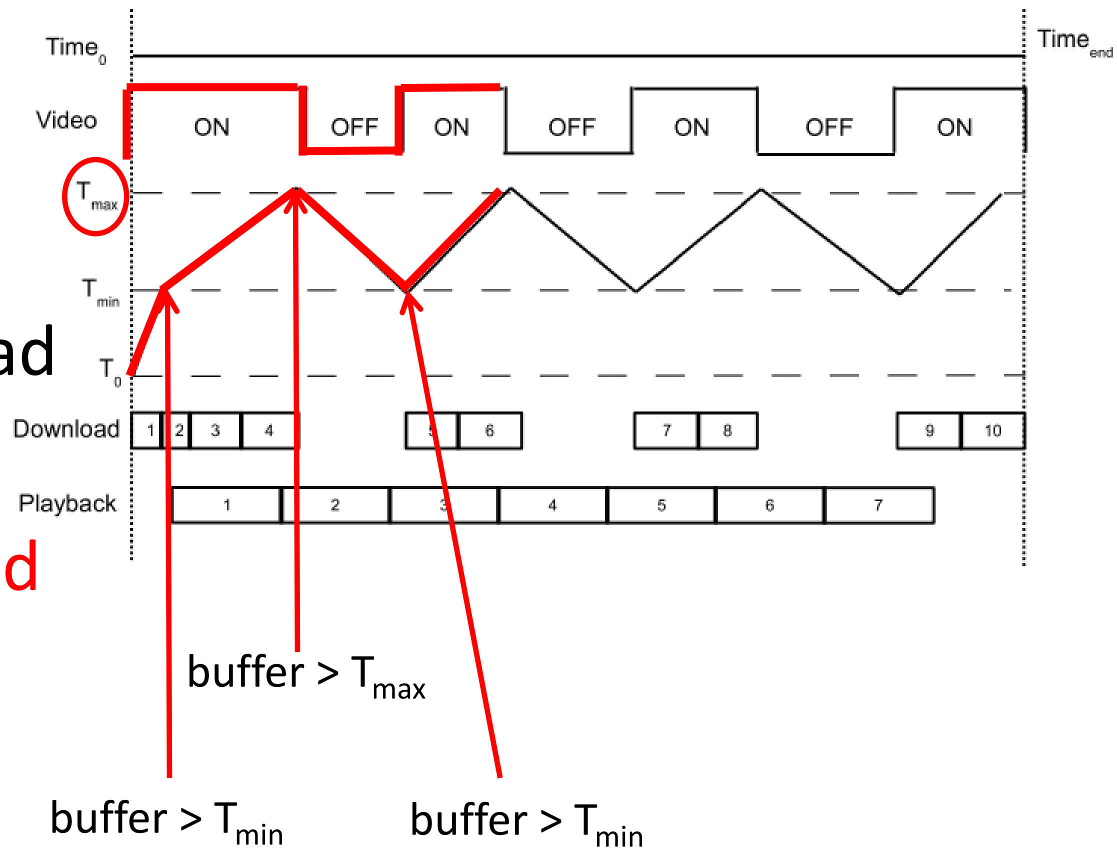
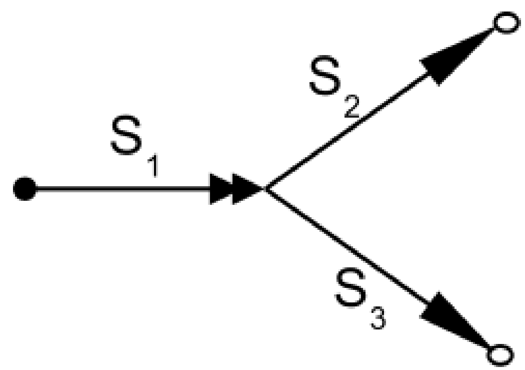


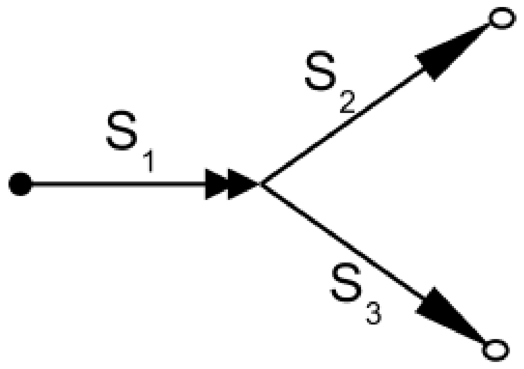
Capped Workahead

- How to handle workahead when video contains branches?



Capped Workahead

- How to handle workahead when video contains branches?
- Perform ON-OFF switching based on number of branches after the closest branch point
  - $T_{min} = T_{single} \cdot$ (# branches)
  - $T_{max} = T_{single} + \Delta$



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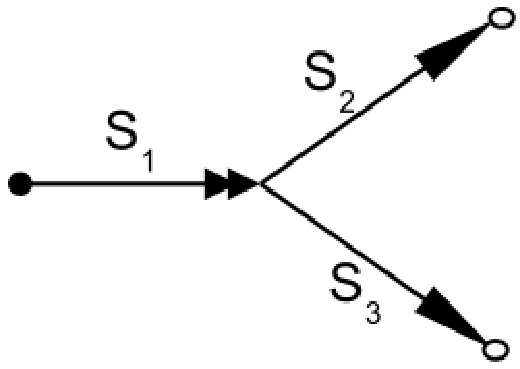

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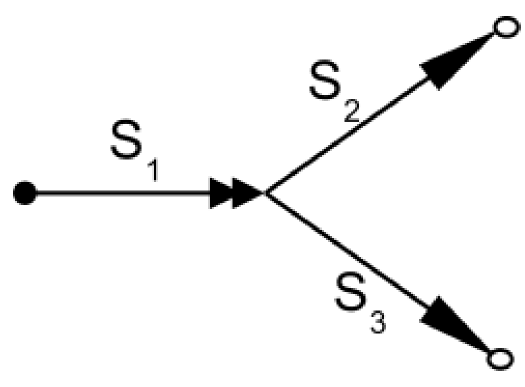

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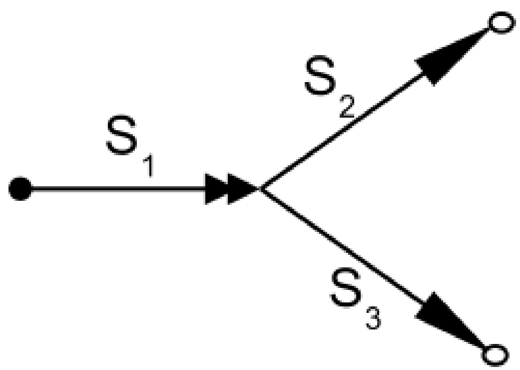

$T_{single} = 8$
$\Delta = 4$
branches = 2

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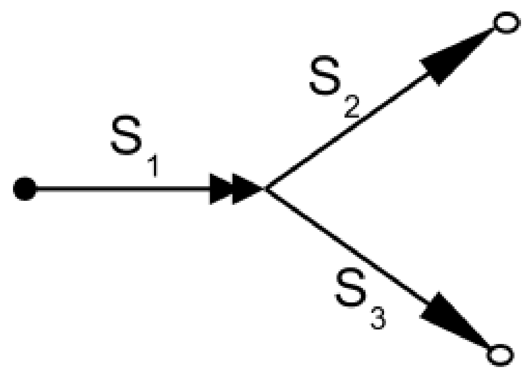
  - $T_{max} = T_{single} + \Delta$

Example



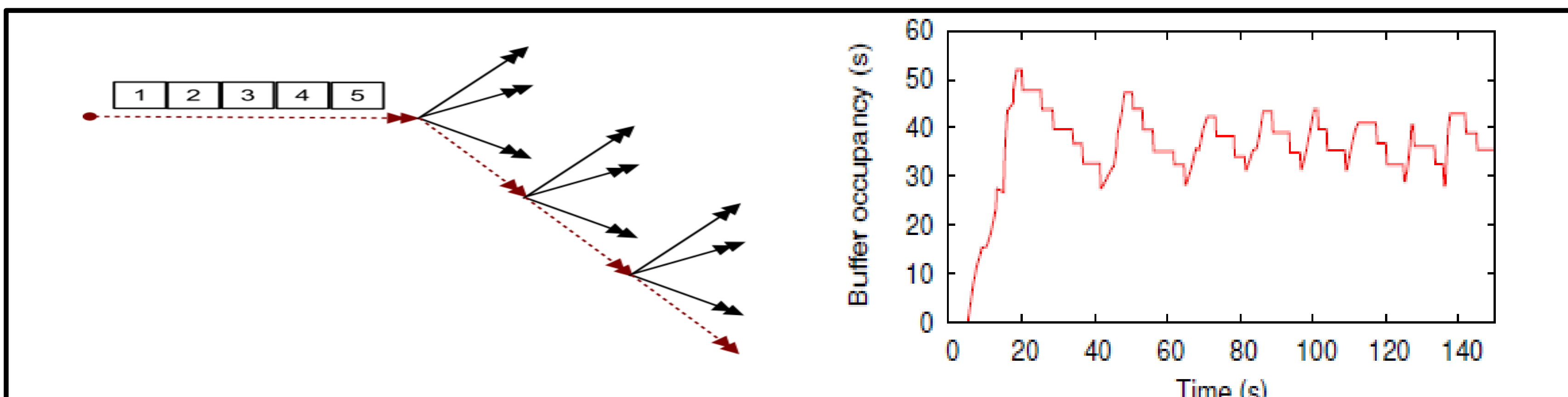
$T_{single} = 8$
$\Delta = 4$
branches = 2

$T_{min} = 16$
$T_{max} = 20$

Capped Workahead

- How to handle workahead when video contains branches?
- Perform ON-OFF switching based on number of branches after the closest branch point
  - $T_{min} = T_{single} \cdot$ (# branches)
  - $T_{max} = T_{single} + \Delta$

Example



Conclusion

- Designed and implemented branched video player that achieve seamless streaming without playback interruptions
- Designed optimized policies that maximize playback quality while ensuring sufficient workahead to avoid stalls
- Evaluation shows that solution effectively adapt quality levels and number of parallel connections so as to provide best possible video quality, given current conditions

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Software: http://www.ida.liu.se/~nikca/mm14.html

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